Southern African Journal of Anaesthesia and Analgesia 2019; 25(5):S10-16

South Afr J Anaesth Analg
ISSN 2220-1181 EISSN 2220-1173

PACSA SUPPLEMENT

Difficult airway management in children

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It is fortunate that the majority of children will have airways that are simple to manage. However, in a small number of cases difficulty may be encountered. The focus of any airway management technique is to provide adequate oxygenation and ventilation. In a cooperative adult, this can be achieved by performing awake intubation techniques, however in children it is often impossible to manage them without performing anaesthesia or deep sedation. In this situation, there are three main ways that airway management is accomplished:

- Face mask ventilation
- Supraglottic airway device ventilation
- Endotracheal intubation

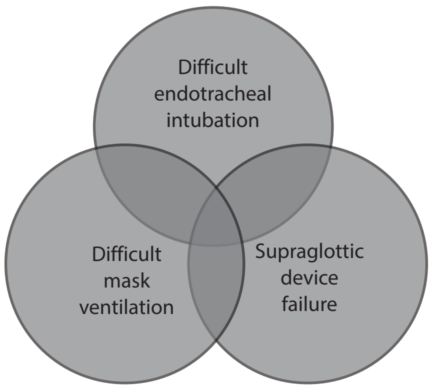

Figure 1. What makes an airway difficult?

There is no formal definition of what constitutes a difficult airway, but from a practical perspective it should be thought of as difficulty with any of the techniques used to provide oxygenation and ventilation. The area of difficulty where all three of the main techniques used to oxygenate a patient converge is the most worrying situation (Figure 1). The incidence of children who are difficult to intubate also experiencing failure of supraglottic device and mask ventilation is unknown, but it can rapidly lead to a 'can't intubate, can't oxygenate' (CICO) event with immediate life-threatening consequences. Multiple guidelines have been produced to aid anaesthetists in the management of the paediatric difficult airway (e.g. https://www.das.uk.com/guidelines/paediatric-difficult-airway-guidelines and http://www.anzca.edu.au/documents/ps56-2012-guidelines-on-equipment-to-manage-a-diff.pdf).

This review will discuss each aspect of airway management and the existing evidence that should be used when deciding how to approach a child with a difficult airway.

Pre-anaesthetic assessment and preparation

Before initiating anaesthesia a thorough medical history and physical examination should be performed. There are several factors that may point to a child being at risk for having a difficult airway.[1] These are summarised in Table I. Additionally, it is important to ask about previous anaesthetics and if possible, interrogate previous anaesthetic records for a formal description of previous airway management techniques. It should be noted that approximately 20% of difficult intubations in children are unanticipated,[2] so every anaesthetic plan should include back-up contingencies to cope with unexpected difficulty with airway management. Children who weigh less than 10 kg are also more likely to experience complications related to airway management.[2] When difficulty is anticipated, planning should take into account the location where the airway management will occur, the equipment required, and personnel needed to minimise complications. The safest place to manage an anticipated difficult airway is in the operating room.[3] The equipment required will vary depending on the circumstances. Advanced airway equipment from the anaesthetic team (e.g. flexible bronchoscopes, videolaryngoscopes) can be supplemented by the presence of our ENT surgical colleagues

Table I. Factors that may predict a difficult airway in children[1]

Soft tissue pathology	Tumour Abscess Scars Previous radiotherapy Burns
Maxillofacial malformations	Mandibular hypoplasia Micro/retrognathia Asymmetrical facies Reduced mouth opening
Intraoral anomalies	Microstomia Macroglossia Large overbite
C-spine pathology	Decreased mobility Instability
Airway obstruction	Stridor Obstructive sleep apnoea

and their equipment (e.g. rigid bronchoscopes, tracheostomy). Another essential feature of the management of the difficult airway is clear communication between all those involved, particularly if the airway needs to be shared with a surgical team. Any plan should be fully discussed with the nursing and surgical staff, and if needed, explicit recognition of everyone's role, and when roles may be exchanged (e.g. when the surgical team should take over attempts at intubation if the anaesthetic team have been unsuccessful).

Difficult mask ventilation

Difficulties ventilating children with a face mask occur in approximately 6% of cases.[4] Physical features that should be observed during the physical examination that may be associated with difficult mask ventilation include:

- Micro/retrognathia
- Craniofacial abnormalities
- Cervical spine abnormalities
- Obesity
- Obstructive sleep apnoea (OSA)

Positioning the patient 'head up' at approximately 30 degrees and the use of airway adjuncts such as oral or nasopharyngeal airways may improve the ability to ventilate via a face mask. If the patient has significant anatomical abnormalities, such as a base of tongue tumour or a neck mass, that make it difficult to bypass the obstruction with an airway adjunct, maintaining spontaneous breathing may be safer than a technique reliant on positive pressure ventilation.

Infants and neonates who experience difficult mask ventilation are at risk of developing significant gastric distension. This can impact on the ability to oxygenate, cause rapid oxygen desaturation through atelectasis and decreased functional residual capacity, resulting in less time available to attempt definitive airway management.

If difficult mask ventilation occurs there are several strategies that can be used to try to improve it:

- Early use of airway adjuncts such as oral/nasopharyngeal airways
- Two-person technique with a two-handed jaw thrust and a second person manually ventilating
- Change of head and/or patient position
- Early decompression of the stomach
- Early use of alternative technique, particularly a supraglottic airway

Difficult supraglottic device ventilation

Supraglottic devices were first described for use in adults in 1983.[5] Over the intervening decades many different supraglottic devices have been created for use in children. At the time of writing these include[6,7]:

- AirQ and AirQ SP
- Ambu AuraGain, Ambu Aura-i and Ambu AuraOnce
- Cobra
- I-gel
- Laryngeal tube
- LMA Classic, Flexible, ProSeal, Supreme and Unique
- PRO-Breathe
- SLIPA
- Softseal

When considering their use in children with difficult airways, the main concern is the risk that a device will fail to provide adequate oxygenation and ventilation. The available evidence examining the failure rates of different devices in children with normal airways is summarised in Table II. The rate of failure depends on the type of device and the individual child. Anatomical features associated with the presence of a difficult airway will tend to increase the risk of a supraglottic device failing.

Table II. Failure rates of supraglottic devices in children[7]

Device	Failures/total cases	% (95% CI)
AirQ	0/126	0 (0-3.0)%
AirQ SP	1/69	1.4 (0.26–7.8)%
Ambu AuraGain	0/50	0 (0–7.1)%
Ambu Aura-i	0/32	0 (0–10.7)%
Ambu AuraOnce	2/132	1.5 (0.42–5.4)%
Cobra	4/301	1.3 (0.52–3.4)%
I-gel	37/1 079	3.4 (2.5–4.7)%
Laryngeal tube	2/108	1.9 (0.51–6.5)%
LMA Classic	4/1 118	0.36 (0.14–0.92)%
LMA Flexible	0/69	0 (0–5.3%)%
LMA ProSeal	6/1 211	0.50 (0.23–1.1)%
LMA Supreme	9/488	1.8 (0.97–3.5)%
LMA Unique	2/410	0.49 (0.1–1.8)%
PRO-Breathe	6/100	6.0 (2.8–12.5)%
SLIPA	0/50	0 (0–7.1)%
Softseal	0/36	0 (0-9.6)%
Total	75/5 379	1.4 (1.1–1.7)%

It is not possible to choose a single supraglottic device to recommend over others for use in children. In general, second-generation devices (those with oesophageal and laryngeal outlets) are considered superior to the original supraglottic devices as they demonstrate:

- Higher seal pressures
- Increased ease of insertion
- Oesophageal lumens allow access to the stomach to help prevent aspiration and enabling decompression of the stomach whilst continuing to ventilate

The correct choice of device will be influenced by the patient, and the reason for using the device. For example, a recent network meta-analysis by Mihara et al. in 2017 compared the current supraglottic devices available for use in children.[7] In this study, the authors concluded that the LMA-ProSeal may overall be the best supraglottic airway device for use in children. However, if the intent is to use the supraglottic device as a conduit to facilitate tracheal intubation, the LMA-ProSeal could be considered a poor choice when compared to the AirQ laryngeal airway, or the i-Gel.

It is also important to emphasise the early use of supraglottic devices when confronted by an unanticipated difficult airway in children. They may be life-saving when used to facilitate oxygenation during airway management and, as mentioned above, have been used as a conduit to facilitate tracheal intubation when used in combination with flexible bronchoscopy.[8]

Difficult tracheal intubation

Difficult tracheal intubation in the paediatric population is estimated to occur in 0.28–1.35%[2,9] of patients. Predictors of difficult intubation in children include extremes of weight, younger age, increased illness severity as measured by the American Society of Anesthesia (ASA) classifications, and types of surgery such as cardiac or oromaxillofacial surgery that may also serve as a surrogate for associated congenital abnormalities.[1,2] Nearly 20% of difficult intubations are not anticipated.[3] Common physical examination findings associated with difficult intubation include micrognathia, limited mouth opening and cervical spine immobility.[3] In 2012 the Pediatric Difficult Intubation Registry (PeDIR) was formed under the auspices of the Society for Pediatric Anesthesia in the USA. This registry is a multinational database that, at the time of writing, contains over 4 000 cases of difficult paediatric intubation, that has been used to gather data on this vulnerable population. The registry revealed that severe hypoxia occurred in 9% of these children, with cardiac arrest occurring in nearly 2%.[2] Every cardiac arrest was preceded by hypoxia. This demonstrated that during difficult tracheal intubation, maintenance of oxygen saturations should be our first priority.

Tracheal intubation can be accomplished by many different techniques.

Direct laryngoscopy (DL)

DL remains the most commonly chosen technique for tracheal intubation in children. It was used in 98% of cases in the Apricot study examining over 31 000 anaesthetics in 261 institutions in Europe,[9] and was the first choice technique in nearly half of the patients in the PeDIR.[2] Unfortunately, DL has a low success rate in children who are difficult to intubate, with first attempt success rates of 4% and eventual success rates of only 21%.[10] Given these poor success rates, DL has a limited role in the management of anticipated difficult intubation. If used as a first choice, it is imperative that back-up plans are in place to ensure a rapid progression to more advanced techniques. However, complications associated with intubation are related to the number of attempts at intubation,[10,11] so choosing a technique with higher first pass success rates is sensible (Table III).

Table III. Success rates of different intubation techniques from the Pediatric Difficult Intubation Registry[2,8,10]

Technique	First attempt success	Eventual success
Direct laryngoscopy	4%	21%
Flexible bronchoscope	Not reported	53%
Hyperangulated VL (GlideScope)	53%	82%
Intubation through an SGA	59%	89%

Videolaryngoscopy (VL)

Videolaryngoscopes use video cameras embedded within the laryngoscope blade to obtain a view of the larynx. They can be thought of as two distinct types:

1. Hyperangulated videolaryngoscopes
2. Standard bladed videolaryngoscopes

Hyperangulated devices cannot be used to directly visualise the larynx because they do not allow alignment of the oral, pharyngeal and laryngeal axes in the same fashion as standard laryngoscopy blades. Hyperangulated VLs look around the curve of the airway and rely solely on the view provided by the video camera. Hyperangulated blades include the GlideScope, Airtraq, Pentax AWS, Truview and the Storz C-Mac D-Blade.

Standard blade videolaryngoscopes are identical to traditional DL blades, but have a camera mounted distally within the blade. This allows DL to be performed, but also provides a second point of view (video-assisted DL–VADL) that may give a better view of the larynx, and allow others to view the endotracheal tube passing through the vocal cords. Standard laryngoscope VL systems include the Storz C-Mac Macintosh and Miller blades, McGrath Mac blades and the UE Scope. VL has been shown to achieve better views of the larynx when compared to DL,[12,13] but there has been a suggestion that it may increase the time taken to intubate by approximately five seconds.[14] This has not been shown to increase complications, and in particular there is no evidence that VL use is associated with a greater incidence of hypoxia.

In the PeDIR database, the hyperangulated GlideScope (GVL) was the most frequently used video system, accounting for 76% of all VL use. Park et al. compared GVL with DL use in children in the PeDIR and found that GVL had much higher initial and eventual success rates. The initial success rate with the GVL was 53%, with an eventual success rate of 82%, compared to just 4% and 21% with DL.[10] Interestingly, the success rates of GVL were significantly lower in children weighing less than 10 kg with initial success rates of 39% and eventual success in 73%. In adults, the success rate of GVL following failed DL is greater than 90%,[15] so the success rate of GVL in children and particularly infants, is significantly lower. Possible reasons for the lower success with GVL in children compared with adults include the more rapid oxygen desaturation seen in children, increased technical difficulties when using smaller equipment, and possibly inappropriate blade size selection. This study also showed no difference in the rates of hypoxia or trauma when using GVL or DL. This was confirmed in a prospective study comparing videolaryngoscopy and direct laryngoscopy in patients predicted to be difficult intubations, which also showed no difference in rates of airway trauma or desaturation.[16]

One of the drawbacks of hyperangulated VL is that even if the larynx is clearly visualised, it may not be possible to pass the ETT into the trachea due to the angulation of the larynx with respect to the laryngoscope blade. Different methods to combat this have been described, including using stylets in different configurations to pre-shape the ETT,[17-19] or using a flexible bronchoscope as a manipulatable stylet to enter the trachea.[20]

Flexible bronchoscopic intubation (FBI)

Awake flexible bronchoscopic intubation has been shown to be a safe and effective method of securing potential difficult airways in adults, with a failure rate of ~1%.[21] Most children will not tolerate awake or even sedated airway management, so FBI is most commonly performed after induction of general anaesthesia. Despite advances in videolaryngoscopy, FBI remains an essential technique for difficult airway management in children. It may be the only option (aside from tracheostomy) for patients with limited or no mouth opening that precludes laryngoscopy or supraglottic airway placement. FBI was the choice for initial airway management in ~1/3 of the patients in the PeDIR.[2]

There are limited data assessing the safety and effectiveness of FBI in children who are difficult to intubate. Within the PeDIR, FBI had a first pass success rate of 38% in patients weighing less than 10 kg and 54% in those more than 10 kg. In a mannequin study simulating a difficult airway in a child with Robin sequence, Fiadjoe et al. compared first attempt intubation success between Glidescope and FBI amongst attending anaesthesiologists at two major paediatric centres. They found no difference in intubation success rates.[22] FBI has also been described as a successful technique in real infants with Robin sequence,[23,24] but it should also be considered an important part of combined techniques such as intubation via a supraglottic airway, or when used with VL.

Supraglottic airway as a conduit to flexible bronchoscopic intubation

A supraglottic airway can often bypass the causes of upper airway obstruction and in most cases provides direct access to the larynx. It is possible to perform FBI through a supraglottic device by passing a flexible bronchoscope through the lumen of the device and into the trachea. An endotracheal tube can then be railroaded over the flexible bronchoscope into the trachea. This technique has the advantage of allowing continuous oxygenation to occur via the SGA, and may even allow continuous ventilation depending on the size of the ETT and FBI used.[25] In neonates and young infants, awake supraglottic airway placement is generally well-tolerated and allows for assessment of adequate placement prior to induction.[24-26] Among the FBI-SGA patients entered into the PeDIR, rates of hypoxia were significantly lower when continuous ventilation was used during intubation (7% vs. 25%, $p = 0.04$).[8] The AirQ laryngeal airway was the most commonly used SGA to facilitate FBI in children. In a study comparing the AirQ assisted technique with a 'free-hand' approach in children younger than two years of age, no differences were found in the number of attempts needed to intubate, or the time taken. However, there were less adjustments needed to optimise the view of the larynx if the AirQ was used.[27]

Other combined techniques

There are numerous case reports describing techniques combining different airway management techniques. As an example, laryngeal visualisation is often possible with hyperangulated videolaryngoscopes, but navigating the endotracheal tube into the trachea can be problematic. Flexible bronchoscopic intubation combined with hyperangulated VL allows for two vantage points to view the airway and the flexible bronchoscope can be used as a movable stylet to guide the ETT into the trachea.[20,28] The ability to view the glottis with the GVL whilst advancing the ETT over the flexible scope can help identify and solve problems that may occur, with the aim of decreasing potential trauma from blind, forceful ETT advancement.

Other combined techniques described include both hyperangulated videolaryngoscopy and video-enhanced direct laryngoscopy in combination with an optical stylet, light wand, or flexible bronchoscope.[29-31]

Supplemental oxygen administration during airway management

Children can experience rapid oxygen desaturation during airway management. This occurs because of their high rate of oxygen consumption coupled with a lower functional residual capacity. The use of supplemental oxygen during routine airway management is not currently recommended, however in the setting of a difficult airway, it should be used. When supplemental oxygen is administered during intubation, a significant increase in the time to oxygen desaturation has been demonstrated.[32-34] Techniques have included administering oxygen via nasal cannula,[35] through the laryngoscope[32,34] and through specific equipment designed to deliver high flow, humidified oxygen (e.g. Transnasal Humidified Rapid Insufflation Ventilatory Exchange [THRIVE]).[33,36] The THRIVE system has been shown to maintain oxygen saturations for at least twice as long as the expected age-dependent apnoea times in healthy children.[33]

Steiner et al. examined the use of 'deep' oxygen insufflation via a PCD Truview videolaryngoscope, through its side-port attached to an oxygen supply, and a modified traditional direct laryngoscope blade. They compared the time to oxygen desaturation using these devices compared to traditional direct laryngoscopy without oxygen supplementation, in apnoeic children.[34] The graph below illustrates their results, showing that children without supplemental oxygen desaturated much more rapidly:

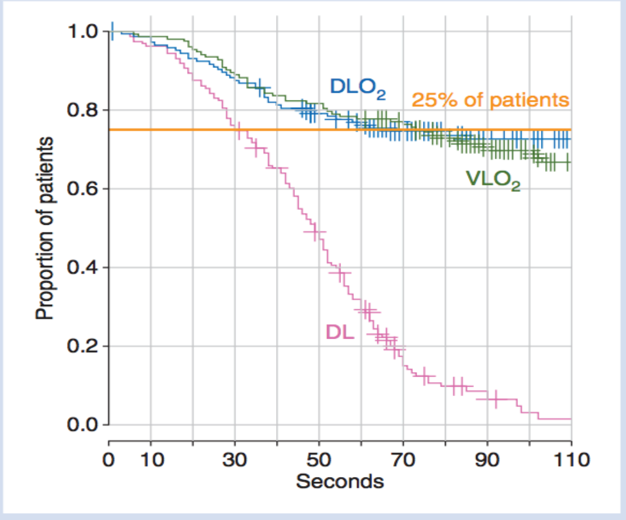

Figure 2. Kaplan-Meier curves of time to 1% reduction in saturation from the baseline. Time to 1% reduction in saturation was censored at the end of intubation.[34]

Riva et al. also studied the effect of oxygen administration via standard nasal cannula versus the use of the THRIVE system in children. They studied apnoeic children receiving 100% inspired oxygen using THRIVE or via low-flow nasal cannula (0.2 litre kg^{-1}) and 30% oxygen using THRIVE.[37] Their results demonstrated an increase in apnoea times in both groups given 100% oxygen, but not in the 30% group. These studies support the use of supplemental oxygen administration during intubation attempts to increase the time to desaturation and increase the time available for practitioners to secure the airway.

There is clear evidence that the use of supplemental oxygen can increase the time to oxygen desaturation during airway management. It should be used whenever a difficult airway is encountered. A recent editorial by Fiadjoe and Litman also addressed this issue,[38] concluding that oxygen supplementation should be used on all expectedly difficult or prolonged intubation attempts in children. The benefit-to-risk ratio is too great to ignore.

Muscle relaxation

Compared with the adult literature, there is less evidence in children to support the use of neuromuscular blockade (NMB) to optimise intubating conditions. A recent Cochrane review included 34 studies evaluating the influence of neuromuscular blockade on outcomes in tracheal intubation in adolescents and adult patients. Avoidance of NMB was statistically significantly associated with difficult direct laryngoscopy (RR 13.27, 95% CI 8.19–21.49, P = 0.00001).[39] There is more limited evidence in children that neuromuscular blockade improves intubating conditions. In contrast to the adult reviews on this topic, only seven studies met criteria for inclusion for a recent meta-analysis evaluating NMBA use and intubating conditions in children.[40] This study concluded that muscle relaxants may be recommended for intubation over opioids to improve intubation conditions. Of note, all the included studies in this meta-analysis compared intubating conditions between patients receiving muscle relaxant to those receiving a combination of opioids and volatile anaesthetics. The doses of opioids administered in these studies could be expected to render patients apnoeic, therefore the conclusions from these studies may not be applicable in answering questions concerning safety and effectiveness in spontaneously breathing patients. The characteristics of the trials included in the meta-analysis are outlined in Table IV.

There is no evidence that maintaining spontaneous breathing decreases the risk of complications and hypoxia during airway management. Indeed, the opposite may be true, in that complications such as laryngospasm and hypotension from the higher doses of anaesthesia required may occur when neuromuscular blockade is avoided.

The most recent study using data from the PeDIR examined the differences in complications in patients who were breathing spontaneously versus those who underwent controlled ventilation with and without muscle relaxation. The initial hypothesis was that those breathing spontaneously would experience less complications than those who were rendered apnoeic, however, the opposite was found to be true. The spontaneously breathing group was more than twice as likely to experience complications than the apnoeic group. Interestingly there were no differences in complications between the group that was paralysed and those rendered apnoeic without neuromuscular blocking agents, so it is possible that the complications seen in the spontaneously breathing group relate to inadequate depth of anaesthesia, although it is not possible to confirm this with a retrospective review.

Table IV. Characteristics of the trials included in the meta-analysis[40]

Paper	Patient age	Anaesthetic agent and dose	Opioid and dose	Muscle relaxant and dose
Blair et al.[41]	3–12 years	Propofol (3 mg kg^{-1})	Alfentanil (10 mcg kg^{-1})	Succinylcholine (1 mg kg^{-1})
Blair et al.[42]	3–12 years	Propofol (3 mg kg^{-1})	Remifentanil (1–3 mcg kg^{-1})	Mivacurium (0.2 mg kg^{-1})
Crawford et al.[43]	2–12 months	Propofol (4 mg kg^{-1})	Remifentanil (2 mcg kg^{-1})	Succinylcholine (2 mg kg^{-1})
Devys et al.[44]	1–24 months	Sevoflurane (8% inspired)	Alfentanil (20 mcg kg^{-1})	Rocuronium (0.3 mg kg^{-1})
Morgan et al.[45]	2–16 years	Propofol (4 mg kg^{-1})	Remifentanil (1.25 mcg kg^{-1})	Succinylcholine (1 mg kg^{-1})
Ng and Wang.[46]	2–10 years	Halothane (3% inspired)	Alfentanil (20 mcg kg^{-1})	Succinylcholine (2 mg kg^{-1})
Steyn et al.[47]	2–14 years	Propofol (3–4 mg kg^{-1})	Alfentanil (15 mcg kg^{-1})	Succinylcholine (1.5 mg kg^{-1})

Our current practice is to recommend the use of neuromuscular blockade in the majority of patients and to maintain spontaneous respiration in patients who have anatomically obstructing lesions that are not possible to bypass with airway adjuncts (e.g. large neck masses causing tracheal deviation, large mediastinal masses compressing the airway, etc.). In patients where controlled ventilation has been established with a mask or supraglottic device, we consider it safe to administer neuromuscular blockade and recommend it to ensure optimal intubating conditions are achieved for the first attempt at intubation.

Front of neck access (FONA)

In the rare, but potentially catastrophic 'Cannot Intubate, Cannot Oxygenate' (CICO) scenario, emergency front of neck access (eFONA) will be the technique of last resort to restore the ability to oxygenate the patient. Options to accomplish eFONA include surgical approaches via a cricothyrotomy or tracheostomy, or utilising a Seldinger approach with needle cricothyrotomy. Once the trachea is accessed, oxygenation can be supplied using jet-ventilation through the cannula or from an alternate oxygenation source.

The Difficult Airway Society has released guidelines recommending a surgical approach for eFONA using a 'scalpel, twist, bougie, tube (STBT)' technique. The steps for this technique involve a scalpel incision through the cricothyroid membrane, followed by a twist to widen the tract. A bougie is inserted into the trachea, then an endotracheal tube railroaded over the bougie. This technique has been demonstrated to be successful, even in the most adverse conditions. Using this technique, Lockey et al. reported a 100% success rate in 98 pre-hospital STBT cricothyrotomies. Mabry also described an 85% success rate of cricothyrotomy using the STBT technique when utilised by battlefield physicians in Afghanistan.

Infants and neonates in particular pose a challenge to performing an STBT approach due to their smaller airway dimensions. In this population, even a neonatal size endotracheal tube may have a larger outer diameter than the size of the average neonatal cricothyroid membrane, complicating the ability to utilise an STBT technique. As an alternative, a cannula-based approach that relies on a smaller catheter placed into the trachea, either through the cricothyroid membrane or trachea itself, can be used. This may prove less traumatic. A study from 2015 performed in rabbits, compared needle cricothyrotomy with surgical techniques for eFONA.[48] In this study, the animals chosen weighed approximately 4 kg in order to simulate procedural conditions in neonates/infants. While the study noted difficulty with both techniques, needle cricothyrotomy had 100% success while surgical techniques, a 75% success rate.

There is currently insufficient evidence to recommend a given technique for eFONA in children. While anaesthetists may have greater comfort with needle-based techniques, STBT may be more effective in older children and adolescents. Newer emergency oxygenation and ventilation devices such as the Ventrain,[49] that allow for both oxygenation and ventilation via a small lumen catheter may be beneficial, though at this time there is minimal evidence on its use in children[50,51] and it is not licensed for use in children by the FDA in the USA.

Conclusion

Though airway management is children is generally uncomplicated, children who prove to be difficult to intubate can be susceptible to significant complications. In particular, when difficulty is encountered, there is a risk of hypoxia and hypoxia-related cardiac arrest. Complications are associated with increased intubation attempts therefore strategies to best minimise risk in this patient population include:

- Mitigating risk of hypoxia through adequate preoxygenation and providing supplemental oxygen throughout airway management.
- Optimising conditions for successful first attempt at intubation by considering advanced airway techniques rather than direct laryngoscopy if difficulty is anticipated.
- Utilising muscle relaxation to provide the best possible conditions for intubation provided there is assurance that the patient can be safely ventilated.
- In the setting of failed intubation, there should be rapid progression to alternate techniques and to the most experienced provider.

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