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Update on Airway Devices

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Abstract There has been a number of newer airway devices aimed to improve airway management for children. Cuffed tracheal tubes (TT), videolaryngoscopes (VLs) and supraglottic airways (SGAs) have all been used successfully in the clinical practice of pediatric anesthesia. The purpose of this review article is to present the current evidence regarding the use of the Microcuff TT, alternative devices for direct laryngoscopy (fiberoptic bronchoscopes and VLs) and newer SGAs (LMA Supreme, i-gel, and air-Q) in infants and children.

Keywords Supraglottic airway devices · Difficult pediatric airway · Cuffed tracheal tubes · Flexible fiberoptic bronchoscope · Pediatric videolaryngoscopes · LMA Supreme · i-gel · air-Q

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Introduction

The focus of this review is to provide an overview of newer pediatric airway devices: cuffed pediatric TTs, newer supraglottic airways (SGAs), and alternatives to direct laryngoscopy (DL) (fiberoptic bronchoscopy and videolaryngoscopy), with an emphasis on their utility in the management of the abnormal pediatric airway.

Microcuff TT

For more than 50 years, uncuffed TTs have been the gold standard for pediatric tracheal intubations, despite several shortcomings [1]. These limitations include airway leaks leading to inaccurate measurements of tidal volumes, end-tidal anesthetic concentrations, capnography tracings, as well as increased waste of inhaled anesthetics, pollution of the operating room, and risk for airway fires [2–4]. The inability to seal the airway during dynamic changes in lung compliance can lead to inadequate ventilation of the lungs and necessitate tracheal reintubation with another TT [5••]. These limitations have led to an increased use of cuffed TTs over the past few years, which have not been associated with complications in children [5••, 6, 7]. There are conflicting views on the use of cuffed TTs in children arising from their susceptibility for pressure related injuries at the level of the non-distensible cricoid ring, which is functionally, the narrowest part of the neonatal airway [8, 9]. Post-extubation stridor is a known complication of airway injury related to the use of cuffed TTs and can be attributed to cuff hyperinflation and inadequately designed cuffed TTs [4, 10]. Many available cuffed TTs may be inappropriately sized for children, as variations in the TT outer diameters exist among manufacturers. Furthermore, the absence of adequate depth

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markers can be a significant safety issue (i.e., endobronchial intubation) [11]. An ideal pediatric cuffed TT should have a short, high-volume, low-pressure cuff that is distal enough to avoid contact with the cricoid ring, have depth markings to guide proper positioning below the subglottic region, and have a standardized ratio of inner to outer TT diameter for appropriate sizing [4, 12•]. The Microcuff® (Halyard Health (formerly Kimberly-Clark Health Care); Alpharetta, Georgia, USA) is a newer TT that was designed for the pediatric airway and features a high-volume/low-pressure, shortened, ultrathin polyurethane cuff that is more distally located on the TT, and lacks a Murphy eye. The distally positioned cuff reduces the risk of unwanted pressure at the cricoid ring and decreases the risk for endobronchial intubation or intralaryngeal placement of the cuff, which are potential problems for shorter infant tracheas.

A large multi-center study involving over 2000 children demonstrated a similar incidence of post-extubation stridor and fewer TT exchanges with the Microcuff TT compared with uncuffed TTs [5••]. In a separate study, the authors reported that the ultrathin cuff may allow the use of a larger inner diameter TT than traditional cuffed TTs without an increased rate of post-extubation stridor or TT exchange [13]. Although studies in adults demonstrated a correlation between the use of the Microcuff TT and reduced rates of ventilator-associated pneumonia (VAP), similar studies in children have not been forthcoming [14].

Compared with traditional cuffed TTs, the polyurethane cuff of the Microcuff TT provides an effective seal at lower cuff pressures while minimally increasing the outer diameter of the TT [15]. In general, cuff pressures should be continuously monitored ($\leq$20 cm H_2O) in children to prevent complications from unnecessary pressure across the tracheal mucosa, which can lead to ischemic injury and airway edema [5••, 5, 9, 16]. A study found that the Microcuff depth markings allowed for successful placement of the TT in children of all ages, confirmed by endoscopic evaluation [17]. However, this study was limited by the exclusion of children with difficult airways thus limiting the external validity of the findings.

Although the Microcuff TT design is based on the pediatric airway, the manufacturer does not advocate its use in infants <3 kg, and there are very few pediatric studies to date that have been performed with the Microcuff TT in this population. The Microcuff TT is not the definitive cuffed TT in infants, as infants and neonates $\leq$3 kg in weight have been excluded from most clinical studies. Of note, a published report has described post-extubation stridor in smaller infants after tracheal intubation with the Microcuff TT, even with the cuff completely deflated [18]. The TT used may have been inappropriately sized, potentially contributing to these complications [12•]. Additionally, the lack of resistance when passing a TT through the subglottic space does not reliably indicate appropriate sizing, and an audible leak test should still be performed on all TTs. As such, caution should be exercised when using cuffed tubes, including Microcuff TTs, in preterm and full-term neonates, and infants less than 3 kg until further evidence confirms the safety of cuffed TTs in this population. Other practical considerations with the use of the Microcuff TT include the greater cost (3–6 times that of traditional TTs), and the lack of RAE-style cuffed TT options. Table 2 summarizes the features of the Microcuff TT.

The Flexible Fiberoptic Bronchoscope

The flexible fiberoptic bronchoscope is considered the gold standard for securing the difficult pediatric airway. Newer developments in technology and the introduction of VLs have improved airway management options, but have not eliminated the role for flexible fiberoptic bronchoscopes in the practice of anesthesiology. The flexible fiberoptic bronchoscope still holds certain advantages over newer advancements, allowing for orotracheal intubation in patients with restricted mouth opening (which is not possible with VLs), nasotracheal intubation, and facilitating tracheal intubation through a supraglottic airway [19••]. Flexible fiberoptic bronchoscopes are also the only devices that can be used to visualize the lower airways, or aid in the proper positioning of bronchial blockers and double lumen tubes [20]. Furthermore, the flexible fiberoptic bronchoscope is particularly useful in pediatric practice, as it is available in sizes small enough to accommodate children of all ages, including neonates. As an alternative to fiberoptic technology, newer Flexible Intubation Video Endoscopes (Karl Storz Endoscopy-America, Inc., El Segundo, CA, USA) are available in sizes 2.8 mm or larger. These videoscopes differ from their fiberoptic counterparts by utilizing a digital video chip and LED light source in the tip of the bronchoscope for full-sized, clearer images. A disadvantage of the smallest sized fiberoptic bronchoscope (diameter of 2.2 mm) is the lack of a suction port or working channel. Other limitations to the use of pediatric flexible fiberoptic bronchoscopes include the increased level of difficulty in maneuvering and controlling the smallest sized bronchoscopes, and the sensitivity of the image quality to blood and other secretions, a problem shared by the VLs.

Despite being considered an essential skill, at least 30 % of anesthesiologists in practice do not use fiberoptic bronchoscopes with any regularity, and may lack proficiency [21]. Furthermore, there are enough differences in the techniques needed for adult and pediatric fiberoptic bronchoscopy that many clinicians who care for children may not feel comfortable using smaller bronchoscopes, especially in children with difficult airways [22, 23]. A

study on children less than 2 years of age suggests that for clinicians with limited experience with pediatric fiberoptic bronchoscopes, the nasal route may be a useful option, as it may provide a more straightforward path to the larynx and require fewer maneuvers to optimize the view than with the oral route [24•]. Additionally, the use of SGAs as a conduit for tracheal intubation is another option for facilitating tracheal intubation, requiring fewer interventions for adequate glottic views compared with a traditional free-handed fiberoptic tracheal intubation technique [25].

Pediatric VLs

There are several VLs including the Airtraq, Glidescope, Storz VL, and the Truview EVO2 that are now available for use in children. These laryngoscopes consist of a fiberoptic bundle or a video camera attached to an intubating blade that displays the laryngeal view on a monitor or eyepiece. These devices provide a more panoramic view of the larynx that is typically superior to direct laryngoscopy. These devices often require less head and neck maneuvering, and a lower force for tissue displacement than direct laryngoscopy, making them a useful option for patients with cervical instability and difficult airways [26]. Use of VLs involve two distinct procedures: (1) visualization of the glottic opening followed by (2) TT delivery into the trachea. In clinical practice, a VL addresses both of these procedures. Most studies demonstrate that VL provide better glottic views but take a greater amount of time to complete successful tracheal intubation due to the prolonged time for TT delivery [20, 27–30]. In children with known difficult airways, the GlideScope VL has been shown to have significantly better views of the larynx than with DL [31, 32]. A recent meta-analysis demonstrated that VLs improved glottic visualization at the expense of increased times to tracheal intubation (from 33 to 47 s) and increased failures in children with both normal and some difficult airways [33]. At present time, there is insufficient evidence to recommend one VL over another in clinical practice, as all have been used successfully even in the difficult airway (Table 1). Table 1 provides the advantages and disadvantages of fiberoptic bronchoscopes, and the most commonly utilized VLs available for children.

Newer Supraglottic Airways (SGAs)

Supraglottic airways are an established part of routine and emergency airway management. With the introduction of newer supraglottic airways in children, efficacy can only be determined by comparing these devices to those that are already well established (LMA Classic/Unique and LMA ProSeal). SGAs have also been shown to be useful in pediatric difficult airway management, as they allow for rescue ventilation after failed mask ventilation or tracheal intubation attempts [34], and can bypass upper airway obstructions [35, 36] and provide a conduit for fiberoptic-guided tracheal intubation [37–41]. For these reasons, SGAs have been incorporated in various difficult airway algorithms [19••, 42••]. This section aims to present the features of these newer SGAs (LMA Supreme, i-gel, and air-Q) with the current literature and assist clinicians contemplating the use of these devices in their clinical practice.

The LMA Supreme

Features of the LMA Supreme include

1. Single-use rigid airway tube made of polyvinylchloride (PVC)
2. Contains a gastric drain tube that travels through the center of the device and exits out of the leading edge of the mask
3. The ventilating orifices are located on either side of the mask bowl with overlying epiglottic fins to prevent epiglottic trapping
4. Built-in bite block

Several recent randomized trials have shown that the LMA Supreme provided adequate positive pressure ventilation (PPV) parameters in children, easy gastric access, and reduced rates of gastric insufflation with similar [43] or greater airway leak pressures [44] than the LMA Unique. The airway leak pressures with LMA Supreme were less than with the i-gel [45], although the overall clinical performance of both devices was similar including their use for positive pressure ventilation. In a study simulating a difficult airway scenario using cervical collars, the LMA Supreme was associated with greater airway leak pressures, first attempt success rates, and faster times for successful insertion when compared with the i-gel [46]. In another study, the overall clinical performance and airway leak pressures were similar with the LMA Supreme and the LMA ProSeal [47]. Finally, the time to insert the LMA Supreme is less than for the LMA ProSeal [48, 49]. To date, there are only a limited number of studies that assessed the clinical performance of the LMA Supreme in infants.

The i-gel

Features:

1. Single-use non-inflatable mask made of a gel-like thermoplastic elastomer

Table 1 Alternatives to direct laryngoscopy (DL)

Device	Advantages	Disadvantages
Flexible fiberoptic bronchoscopes [19••, 20, 72–74]	Strong evidence base, gold standard Low rate of complications Multiple uses and variety of sizes Allows tracheal intubation through different routes	The smallest bronchoscopes lack a suction channel Difficult to control smaller sizes Image quality sensitive to secretions Difficult to learn fiberoptic skills
Airtraq™ [27, 29, 30, 75–78] (Prodol Meditec S.A., Vizcaya, Spain)	Single use Lower cost Portability	Tracheal intubation times longer than with DL Difficult to place the tracheal tube when using the guide channel
Glidescope™ [27, 28] (Verathon, Bothell, WA, USA)	Large evidence base Provides the most panoramic view of the videolaryngoscopes, despite having a less bulky video-baton Cobalt is disposable	Mean intubation times longer than with DL Superior grades of view versus DL
Storz VL™ [27, 79] (Karl Storz Endoscopy-America, Inc., El Segundo, CA, USA)	Similar in design to standard laryngoscopes, thus pediatric anesthesiologists report ease of use due to familiarity Successfully used in difficult laryngoscopy	Tracheal intubation times longer than with DL in the normal airway
Truview EVO2™ [27] (Truphatek, Ashland, Missouri, USA)	Designed with a port for oxygen delivery Successfully used in difficult laryngoscopy	Tracheal intubation times longer than with DL in the normal airway

2. Epiglottic rest to prevent epiglottic downfolding
3. Gastric access channel (not present in size 1)
4. Built-in bite block

The i-gel has been commercially available in pediatric sizes since 2009. It was designed to have an anatomical fit and improve its airway seal as it approaches body temperature [50]. Additionally, not having an inflatable cuff reduces the risk for injuries related to cuff hyperinflation and may decrease the time for successful insertion [51]. However, several studies in children have suggested that the wider, conical shape of the mask has a potential reason for spontaneous dislodgment of the device after placement and needs to be secured with tape to maintain adequate airway seal [45, 52, 53]. Therefore, bimaxillary taping is recommended.

Recent meta-analyses and systematic reviews [54•, 55•, 56•] found that the i-gel had greater airway leak pressures and superior fiberoptic views, but no differences in the rates of successful insertion, insertion times, or overall complications compared with other SGAs. These findings are consistent with the other randomized trials performed with the i-gel [57, 58]. More recently, a comparison of the air-Q and i-gel found that both devices were effective conduits for fiberoptic-guided tracheal intubation by trainees, but that the i-gel was prone to TT dislodgement during removal of the SGA after tracheal intubation (seen mostly with the size 1.5 i-gel) [59].

Of the newer SGAs available for children, the i-gel has been investigated the most. The existing literature that compares the i-gel with the LMA Classic, LMA Supreme, and the LMA Proseal presents some conflicting conclusions regarding the differences in time to insertion and ease of insertion. However, on balance, the evidence indicates that the i-gel provides superior fiberoptic grades of laryngeal view than the LMA Classic, LMA Supreme, and the LMA Proseal, but at the same time, it has greater airway leak pressures [54•, 55•, 56•]. Therefore, the i-gel may be a suitable alternative to other established SGAs, even in infants.

The air-Q

The air-Q is manufactured in three versions: (1) standard cuffed, (2) self-pressurized (air-Q SP, lacks an inflatable cuff), and (3) air-Q with an esophageal blocker, a second-generation device that allows for evacuation of gastric contents (not yet available for children).

Features:

1. Manufactured as a reusable or single-use device
2. A shortened, wider, curved airway tube
3. Elevated keyhole-shaped ventilating orifice designed to prevent downfolding of the epiglottis
4. Removable 15-mm adapter to allow the passage of cuffed TTs and facilitate with easy the removal process of the device after fiberoptic-guided tracheal intubation

Table 2 Summary of advantages and disadvantages of new supraglottic airway devices and cuffed tracheal tubes

Device	Advantages	Disadvantages
Microcuff™ TT [5••, 9, 13–15] Halyard Health (formerly Kimberly-Clark Health Care); Alpharetta, GA, USA)	Airway seal at lower cuff pressures compared to traditionally designed TTs Cuff distally located to be positioned below the cricoid ring versus traditionally designed TT Depth markings minimize endobronchial intubation	Cost (3–6 times more than standard TTs) Limited evidence for infants <3 kg No RAE tube options
LMA Supreme™ [47, 80–84] (Teleflex, Research Triangle Park, NC, USA)	Single use Gastric drain High success rate on first attempt Suitable for positive pressure ventilation	Lower airway leak pressure than the LMA ProSeal Difficult to use as a conduit for tracheal intubation Insufficient evidence in infants
i-gel™ [45, 46, 50–53, 55•, 58, 85–92] (Intersurgical, Wokingham, Berkshire, UK)	Several clinical trials and meta-analysis demonstrating the efficacy of use during anesthetic maintenance Favorable airway leak pressures to support positive pressure ventilation Favorable fiberoptic views Appears to be stable in the infant population	Tendency for spontaneous dislodgement after placement (bimaxillary taping is recommended) Cost
air-Q™ [61, 63] (Mercury Medical, Clearwater, FL, USA)	Effective in children with difficult airways Can be used as a conduit for tracheal intubation and for airway maintenance Easy to remove device after successful intubation Single use and reusable versions Stable in infants	No gastric drain in pediatric sizes

Evidence for Airway Maintenance

The cuffed air-Q has greater airway leak pressures and superior fiberoptic views of the larynx than the LMA Unique [60] in small children. Similarly, the cuffed air-Q has greater airway leak pressures and superior fiberoptic views when compared with the Flexible LMA [61] in infants <10 kg. In an observational trial, the cuffed air-Q demonstrated lower airway leak pressures than the LMA ProSeal (historical control) [62]. Regarding the air-Q SP, an evaluation of the device in 352 children (including infants) found that airway leak pressures were acceptable with overall low complication rates [63]. When the air-Q SP (size 2) was compared with the LMA Unique (size 2.5), the two devices had similar airway leak pressures, fiberoptic views, and complication rates [64].

Evidence as a Conduit for Tracheal Intubation

The air-Q was also designed to facilitate tracheal intubation with cuffed TTs in infants and children [38, 41, 65]. The air-Q offers some advantages over the traditional laryngeal mask airways [60]. When compared with the Ambu Aura-I (another SGA designed for tracheal intubation), both devices performed well as conduits for tracheal intubation, including similar insertion success rates and time to tracheal intubation [41]. However, the utility of the Ambu Aura-i size 1.5 with cuffed TTs was limited by its narrower airway tube, which could not accommodate the passage of the TT pilot balloons. The removal process of the air-Q after tracheal intubation has been shown to be effective with low risk for inadvertent tracheal extubation when a removal stylet is used to stabilize the TT [38, 65].

The air-Q has been used successfully in children with difficult airways, while allowing for tracheal intubation with cuffed TTs, even through the smallest device sizes [37, 39, 40, 66–69]. Retrospective evaluations of anticipated and unanticipated difficult airways revealed that the air-Q was used successfully as a conduit for intubation in all cases [37, 68]. In smaller infants, however, the size 1 air-Q has been reported to be too large [67], and a 0.5 size air-Q [40, 70] is now available. In children with craniofacial causes of difficult airway leading to airway obstruction (i.e. Pierre-Robin Sequence and Treacher Collins), the air-Q has been shown to provide adequate ventilation and an effective conduit for fiberoptic-guided tracheal intubation [39, 71]. Table 2 summarizes the advantages and disadvantages of the newer SGAs and Microcuff TT.

Conclusion

With the widespread and successful use of newer airway devices in children, there is a growing body of evidence to support their continued use. Although evidence suggests

that cuffed TT such as the Microcuff TT is safe in children, there is limited evidence that they are safe in infants $\leq$3 kg. The flexible fiberoptic bronchoscope has maintained its role as the gold standard for management of the difficult pediatric airway because it provides the most versatility for clinicians. VLs have been used successfully in children with difficult airways, and further research is needed to determine if one VL is superior to another. Newer supraglottic airway devices such as the i-gel™ offer greater airway leak pressures that may be better suited for PPV when compared with other SGAs. The LMA Supreme appears to be another device that may be used for this purpose, but further studies are needed in infants. The air-Q has been shown to be an effective conduit for tracheal intubation in children with difficult airways. Studies on the use of SGAs as the primary airway management technique in this patient population are also promising. Therefore, the choice of a specific SGA should be contextual and determined by the patient's characteristics. Further research evaluating the safety and efficacy of newer SGAs in the infant population is warranted.

Compliance with Ethics Guidelines

Conflict of Interest Lisa Sohn declares that she has no conflict of interest. Razan Nour declares that he has no conflict of interest. Narasimhan Jagannathan has served on a medical advisory board for Teleflex.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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