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Innovations in pediatric airway management

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ABSTRACT

Airway management in pediatric patients poses significant challenges due to anatomical and physiological differences from adults. Airway-related complications remain one of the leading causes of morbidity and mortality. In recent years, substantial innovations have emerged in airway management, including advancements in equipment, education, and algorithm-based approaches. Videolaryngoscopes, next generation supraglottic airway devices, airway ultrasonography, and high-fidelity simulations have improved both safety and success in clinical practice. Additionally, updates in international guidelines such as those from the American Society of Anesthesiologists (ASA) and the Difficult Airway Society (DAS) emphasize the importance of algorithmic strategies in practical settings. This review provides a detailed examination of the unique features of pediatric airway anatomy, novel devices and techniques, comparative algorithmic approaches of current guidelines, and future technological developments, supported by the literature.

Keywords: Pediatric airway, videolaryngoscope, supraglottic airway device, airway management, ultrasonography

PEDIATRIC AIRWAY ANATOMY

The anatomy of the pediatric airway differs significantly from that of adults, and these differences directly influence technical approaches and the selection of devices for airway management:[1-3]

Head proportion: Infants have a relatively larger head and a prominent occiput. As a result, when lying in the supine position, their head tends to flex forward, which can easily lead to airway obstruction.

Tongue: The tongue is relatively larger and softer, occupying a substantial portion of the oral cavity. This can cause obstruction during mask ventilation and laryngoscopy.

Nasal passage: The nasal passages are narrow, and even mild edema can lead to significant respiratory distress. Therefore, caution is required when inserting nasogastric tubes or nasopharyngeal airways.

Epiglottis: In young children, the epiglottis is soft, long, narrow, and often omega (Ω)-shaped. It is more difficult to visualize during laryngoscopy and is prone to trauma.

Laryngeal position: The larynx is situated more cranially (at the level of C3-C4) and anteriorly compared to adults. Therefore, the glottic opening is positioned higher when viewed through the oral cavity.

The narrowest segment of the airway: While the glottis is the narrowest point in adults, in children, the narrowest region is the cricoid cartilage (subglottic area). This anatomical difference influences endotracheal tube selection and the choice between cuffed and uncuffed tubes.

Trachea: The trachea is shorter and narrower in diameter; changes in head position can significantly alter the position of the endotracheal tube.

Airway supporting structures: The cartilaginous and soft tissue components of the airway are more pliable and prone to deformation.

A comparative overview of pediatric and adult airway anatomy is presented in Table 1.

Table 1. Comparison of pediatric and adult airway anatomy

Feature	Pediatric	Adult
Head/occiput	Relatively large	Smaller
Tongue	Relatively large	Smaller
Epiglottis	Soft,long, omega-shaped	Short, firm, flat
Laryngeal position	At C3–C4 level, anterior	At C5–C6 level
Narrowest point	Cricoid cartilage	Glottis
Tracheal length	Short	Long

AIRWAY EQUIPMENT

For safe airway management in pediatric patients, it is essential to have a complete set of basic equipment in various sizes and designs tailored to this population:[2,4]

Face masks: Anatomically shaped silicone masks in a range of sizes specific to neonatology and pediatrics are used. During ventilation, the mask should be appropriately sized to completely cover both the nose and mouth.

Oropharyngeal airway: Used to maintain mouth opening and airway patency in unconscious children or those with reduced muscle tone. Improper sizing-either too large or too small-increases the risk of airway obstruction.

Nasopharyngeal airway: Indicated when oral access is not feasible or contraindicated (e.g., intraoral trauma, tetanus, trismus). However, it is contraindicated in cases of basilar skull fracture or coagulopathy.

Endotracheal tubes (cuffed/uncuffed): In most pediatric cases, cuffed tubes are preferred. Tube diameter and length are calculated based on age and weight; selecting the appropriate size is critical to prevent subglottic injury.

Laryngoscopes: Both Miller (straight) and macintosh (curved) blades in various sizes can be used in pediatric patients. Miller blades are particularly advantageous in neonates and infants.

ADJUNCT DEVICES FOR DIFFICULT AIRWAY MANAGEMENT

In the management of difficult airways, various adjunct devices and techniques play a crucial role in clinical practice alongside standard equipment:[1,5]

Videolaryngoscopes: Provide a wide and clear glottic view without the need for direct line-of-sight visualization. Pediatric-sized blades and accessories enhance success rates in challenging cases.

Fiberoptic bronchoscope: Considered the gold standard in cases involving anatomical anomalies, trismus, or cervical immobilization. Pediatric models with smaller diameters have been developed for safe use.

Bougie: Useful when the vocal cords are not visible but access to the trachea is desired. Pediatric-sized bougies are also available.

Stylets and introducers: Facilitate modification of the tube shape and aid in navigating an anteriorly positioned larynx.

Supraglottic airway devices (SGAs): Provide rapid and reliable oxygenation, particularly when both mask ventilation and endotracheal intubation have failed.

FONA TECHNIQUES (FRONT OF NECK AIRWAY)

FONA is an abbreviation for “front of neck access” and refers to emergency airway access procedures performed in situations where oxygenation cannot be achieved, known as “can’t intubate, can’t oxygenate (CICO)” scenarios.[8,9] FONA techniques differ between adult and pediatric patients.

FONA Techniques in Adults

Surgical cricothyrotomy: Incision of the cricothyroid membrane using a scalpel followed by tracheal cannulation.
Needle cricothyrotomy: Penetration of the membrane with a large-bore needle and administration of jet ventilation.

Specific Considerations for FONA in Pediatric Patients

Anatomical challenges: In pediatric patients, the cricothyroid membrane is extremely thin and narrow; identification and application are particularly difficult in children under 8 years of age.[4]

Risk of complications: Due to the smaller size of tracheal and laryngeal structures and the softness of the cartilages, the risk of significant injury, bleeding, and subglottic stenosis from incorrect procedures is higher compared to adults.

Needle cricothyrotomy: Involves puncturing the membrane with a 14-18G needle and providing oxygen. However, carbon dioxide retention and barotrauma may develop rapidly; therefore, a definitive surgical airway should be established as soon as possible.

Guideline recommendations: Current guidelines such as those from the ASA and DAS do not recommend surgical cricothyrotomy in children under 8 years of age. In emergency situations, needle cricothyrotomy (with jet ventilation) is considered the only recommended technique.[8,9]

The main characteristics of pediatric front-of-neck access (FONA) techniques are presented in Table 2.

Table 2. Characteristics of pediatric FONA techniques

Age Group	Recommended FONA technique	Notes
≤ 8 years	Needle cricothyrotomy + jet oxygenation	Surgical cricothyrotomy is not recommended.
≥ 8 years	Needle or surgical cricothyrotomy	Anatomical feasibility is essential.

Clinical practice: The application of FONA in pediatric airway management should be performed only by well-trained teams, with appropriate indications and prompt decision-making.

ADVANCES IN PEDIATRIC AIRWAY MANAGEMENT: EQUIPMENT AND APPLICATIONS

Videolaryngoscopes[1,5,6,7]

Videolaryngoscopy (VL) has emerged as a technique that can significantly increase intubation success, particularly in difficult airway scenarios and emergency intubations. Recent systematic reviews and meta-analyses demonstrate that VL offers higher success rates compared to direct laryngoscopy, with this advantage being especially prominent in difficult cases.[5] However, the available clinical evidence in the pediatric population remains limited, and the superiority of VL has not been clearly established; there is a recognized need for further randomized controlled trials in this area.[6]

Advanced-generation videolaryngoscopes such as the Glidescope can enhance operator comfort by reducing both subjective and objective cognitive load. This feature provides a significant advantage, particularly for less experienced users.[7] Nevertheless, in certain cases, direct laryngoscopy may be performed more rapidly and may yield similar or even shorter times to first-attempt intubation compared to VL. Therefore, in emergency situations, both the level of preparation and operator experience are critical determinants.

From an educational standpoint, videolaryngoscopes serve as valuable tools for both specialists and trainees by enabling direct visualization of airway anatomy and facilitating the teaching of correct intubation techniques. A comparative overview of the benefits and limitations of VL is provided in Table 3.

Table 3. Advantages and disadvantages of videolaryngoscopy

Advantages	Disadvantages
Risk of esophageal intubation ↓	Impaired view due to oropharyngeal secretions, blood, gastric contents, or fogging
Good glottic visualization	Efficacy may vary among different VL devices
Easy to learn and teach	Not 100% success rate
Does not require alignment of the oral–pharyngeal–laryngeal axis	Expensive and not available in all hospitals
Allows easy identification of edema and other pathological changes	Depth perception may be compromised due to two-dimensional view
Need for neck manipulation ↓	May result in inadequate preparation for difficult airway scenarios
Ergonomic for the user	
Confidence in both user and device ↑	

Considerations for the Use of Videolaryngoscopes

- The selected videolaryngoscope must be appropriate in terms of blade size and type.
- Application of different techniques may be required depending on the clinical scenario.
- A stylet and lubricating agent should be used with the endotracheal tube.
- The endotracheal tube should be shaped to match the angle of the blade.
- Proper hand–eye coordination is essential for successful intubation.

Limitations of Videolaryngoscope Use

- Inadequate mouth opening
- Fogging of the lens
- Presence of secretions
- Bleeding in the airway
- Technical malfunctions or equipment failure

Fiberoptic Bronchoscope[10]

- Fiberoptic bronchoscopy (FOB) is considered the "gold standard" intubation technique in pediatric cases with anatomical variations, airway tumors, syndromic conditions, cervical spine immobilization, or limited mouth opening.
- With advancing technology, ultra-thin fiberoptic bronchoscopes suitable for use in neonates and infants have been introduced into clinical practice.
- FOB can be performed via the oral or nasal route, or through a supraglottic airway device.
- It is preferred in cases involving anatomical abnormalities, airway tumors, or anticipated difficult intubations.

A detailed summary of the procedural steps for performing FOB is provided in Table 4.

Table 4. Fiberoptic bronchoscopy: procedural steps and clinical considerations

Step	Application	Clinical notes
Preparation	The anesthesiologist is positioned at the head of the patient; an appropriately sized pediatric bronchoscope is selected	Pediatric bronchoscopes typically range from 2.2 to 3.5 mm in diameter
Lubrication	The distal tip of the bronchoscope is lubricated with a suitable gel	Minimizes mucosal trauma
Tube Preparation	The endotracheal tube (ETT) is preloaded onto the bronchoscope	The ETT internal diameter should match the bronchoscope size
Advancement	The bronchoscope is advanced via the oral or nasal route, directed beneath the epiglottis	Nasal route is more physiological but carries higher risk of edema
Visualization	The vocal cords are visualized clearly	Aspiration of secretions or blood may be required for optimal view
Intubation	The ETT is advanced through the vocal cords into the trachea	Slow and controlled advancement is essential in pediatric patients

Next-Generation SGA Devices[11-13]

Next-generation supraglottic airway (SGA) devices, such as the I-gel and LMA Supreme, have been increasingly adopted in pediatric anesthesia due to their design innovations. These devices offer several advantages, including the presence of a gastric drainage channel and ease of insertion, which contribute to reduced risk of aspiration and improved airway seal. The I-gel, constructed from a gel-like thermoplastic elastomer, provides a non-inflatable cuff that adapts to the perilaryngeal anatomy, facilitating rapid and atraumatic placement. Similarly, the LMA Supreme incorporates both a gastric channel and an anatomically curved airway tube, supporting safe and effective use during both elective and emergency airway management in children (Table 5).

Table 5. Next-generation supraglottic airway (SGA) devices

Device	Characteristics	Advantages	Limitations
I-gel	Non-inflatable, gel-like cuff design	Rapid placement, low trauma, allows fiberoptic intubation guidance	Limited evidence in smaller pediatric sizes
LMA supreme	Equipped with a gastric drainage channel	Reduced aspiration risk, reliable in emergency settings	Higher cost
LMA proSeal	Dual lumen, higher seal pressure	Better oropharyngeal seal, safe for prolonged use	Placement may be more difficult
Ambu AuraGain	Anatomically curved design with a channel for fiberoptic intubation	Facilitates guided intubation	Requires operator experience

Airway Ultrasonography[14,15]

Ultrasonography (USG) has emerged as a reliable, noninvasive, and bedside-applicable method in the evaluation of the pediatric airway (Table 6).

USG enables direct measurement of airway diameter, tracheal rings, and the glottic level, offering high accuracy in determining appropriate endotracheal tube size, particularly in patients with anatomical variations.[14]

Selecting an endotracheal tube of appropriate size and preventing complications such as subglottic injury and ventilation failure are critically important, especially in pediatric patients.[15]

Subglottic diameter measurement: Assists in determining the appropriate endotracheal tube size.

Verification of tube placement: Ultrasonography can be used to confirm correct endotracheal tube positioning and to visualize tracheal structures and the cricothyroid membrane.

Localization of the cricothyroid membrane: Provides a reliable anatomical landmark for emergency airway access.

Table 6. Clinical applications of pediatric airway ultrasonography

Application	Description	Clinical advantage
Subglottic diameter measurement	Used to determine appropriate endotracheal tube size	Improves tube selection, prevents subglottic injury
Verification of intubation	Confirms correct tracheal placement of the tube	Reduces risk of post-extubation complications
Cricothyroid membrane localization	Identifies anatomical landmarks for emergency airway access	Particularly useful in obese or edematous children
Tracheal ring assessment	Evaluates tracheal anatomy in congenital anomalies	Enables personalized airway planning

SIMULATION AND TRAINING[16-18]

Recently, machine learning-based models that incorporate demographic data such as age, height, weight, and other parameters have been reported to outperform classical age-diameter formulas in predicting appropriate endotracheal tube size.[16] Traditional formulas, such as the Cole formula ([Age/4]+4), have long been used to estimate the appropriate endotracheal tube size in pediatric patients. Although these formulas provide a simple and practical approach in clinical practice, they do not adequately account for inter-individual anatomical variations, such as differences in subglottic diameter, tracheal length, or airway compliance. Consequently, the exclusive reliance on such formulas may increase the risk of selecting an inappropriate tube size, potentially leading to complications including subglottic injury, air leak, or inadequate ventilation. In contrast, imaging-based modalities such as airway ultrasonography, together with artificial intelligence–supported clinical decision support systems, offer a more individualized and precise method by integrating real-time anatomical measurements and demographic data. These technologies therefore have the potential to mitigate the limitations of traditional formulas and enhance both the accuracy and safety of pediatric airway management. Examples of artificial intelligence applications in pediatric airway management are outlined in Table 7.

In the future, integrating machine learning algorithms into clinical decision support systems may allow for personalized and safer airway management in pediatric intensive care and anesthetic practice.

Clinical Benefits

- Faster and safer airway access
- Personalized tube size selection
- Early prediction of difficult airway risk

Table 7. Examples of artificial intelligence integration

Image processing algorithms for estimating subglottic diameter (ultrasound-based)
Risk stratification systems that predict intubation difficulty using preoperative data
Real-time clinical decision support systems (e.g., guidance during videolaryngoscopy)
Digital assistants powered by machine learning that recommend tube size (based on height, weight, age, and gender for appropriate tube diameter prediction)

Airway Management in Pediatrics[1,19]

Pediatric airway management requires a much more meticulous evaluation and preparation process compared to adults due to the unique anatomical and physiological characteristics of children (Table 8). Ensuring a safe airway during the perioperative period necessitates comprehensive preoperative assessment, appropriate equipment selection, recognition of human factors (Table 9), and the integration of effective algorithmic approaches in emergency situations (Table 10). In this context, intra-team communication and multidisciplinary collaboration play a critical role throughout all stages of airway management. Additionally, because airway complications in children can develop rapidly, the entire airway plan should be shared with the team, and alternative strategies should be readily available.

Table 8. Airway management in pediatrics

Stage	Details
Preoperative evaluation	- Medical history and physical examination - Anatomical features may contribute to intubation difficulty - A multidisciplinary approach may be required - Airway plan should be shared with the team
Preoxygenation	- Mask ventilation may be difficult (due to lack of cooperation in children) - Oxygen delivery ensures an oxygen reserve for safe apnea duration
Anesthesia induction	- Adequate anesthesia/sedation must be ensured - Neuromuscular blockade (NMB) should be administered if necessary - Awake intubation may be preferred in selected cases
Apneic oxygenation	- Continuous oxygen flow maintains an open airway - Creates reservoir in the nasopharynx and trachea - Increases intubation success - Prolongs the duration of apnea
Airway management	- Videolaryngoscopy is recommended in infants and neonates - A hyperangulated videolaryngoscope blade may be considered in difficult airways - Alternative airway strategies should be prepared
Extubation	- Not an emergency; safety takes priority - A reintubation plan must be available - Post-extubation complications should be anticipated - Proper equipment and experience are essential

Table 9. Human factors

Component	Explanation
Cognitive aids	Checklists, color-coded medications, and emergency algorithms reduce the rate of error.
Communication	Communication should be bidirectional (closed-loop communication is preferred).
Team communication	Team members should be able to openly express their concerns.
Post-event evaluation	Unsuccessful interventions should be analyzed; strengths and areas for improvement should be identified.

Table 10. Can't intubate, can't oxygenate (CICO) scenario

Age group	Recommended approach
<1 year	Surgical cricothyrotomy is not recommended.
1-8 years	Modified needle cricothyrotomy and use of a tracheal tube are recommended.
≥8 years	Surgical cricothyrotomy may be performed at the level of the 2nd or 3rd tracheal ring.

ALGORITHMIC APPROACH: ASA AND DAS PEDIATRIC DIFFICULT AIRWAY ALGORITHMS[8,9]

ASA (American Society of Anesthesiologists) Pediatric Difficult Airway Algorithm[8]

In the 2022 ASA guidelines, while the adult algorithm serves as the foundation for pediatric patients, several important modifications and cautions have been introduced to accommodate age-related and anatomical differences specific to children (Table 11).

Table 11. ASA pediatric difficult airway algorithm

Step	Method/strategy	Explanation
Preparation	Prepare equipment and alternative plans	Risk assessment, monitoring
Intubation attempts	Intubation with direct or videolaryngoscope	Maximum of 2 attempts; oxygenation after each attempt
Alternative airway	Supraglottic airway device (SGA)	Fiberoptic intubation if necessary
	Mask ventilation	Two-person technique, airway adjuncts, patient positioning
Emergency surgical airway	Surgical airway	Jet ventilation, needle cricothyrotomy

The guideline is structured under the following main headings: preparation, planned intubation, alternative strategies, and emergency surgical airway.

Preparation and Assessment

- In all cases, the risk of difficult airway should be evaluated through detailed medical history and physical examination.
- If there is suspicion: An awake or sedated approach is recommended, and transfer to a tertiary care center should be considered if feasible. Awake intubation or elective invasive airway is preferred.
- Equipment (videolaryngoscope, fiberoptic bronchoscope, SGA, FONA tools), medications (including emergency drugs) must be readily available.
- A multidisciplinary team and communication strategy should be established; roles should be defined in advance.

Intubation Attempts

- Intubation should be attempted using direct or VL; a maximum of two attempts is recommended.
- Oxygenation should be ensured after each attempt; in case of failure, the next step should be initiated without delay.

Alternative Strategies

SGA, fiberoptic intubation

- If intubation fails, a supraglottic airway device (SGA, e.g., i-gel, LMA) should be used to attempt oxygenation.
- Fiberoptic intubation through the SGA can be attempted if necessary.

Mask ventilation

- If mask ventilation fails, two-person technique, airway adjuncts, and optimal patient positioning should be applied.
- Preoxygenation and maintenance of ventilation are essential at this stage.
- If unsuccessful or if ventilation deteriorates, transition to the emergency airway algorithm is indicated.
- If marginal:
- Anatomical or functional obstruction should be excluded or treated.

- If necessary, assistance should be called for invasive airway access or ECMO.

- If impossible (severe hypoxemia):
- Emergency airway management should be initiated.
- If intubation and ventilation cannot be achieved, emergency invasive airway access (e.g., surgical airway) is mandatory.

FONA (Front of Neck Airway) / Emergency Surgical Airway

- If a CICO situation arises, age-appropriate FONA techniques should be applied:
  - o <1 year: Surgical cricothyrotomy is not recommended.
  - o 1-8 years: Modified needle cricothyrotomy and use of small-diameter tracheal tube are recommended.
  - o >8 years: Surgical cricothyrotomy can be performed at the appropriate tracheal level.

Critical Points

Throughout the algorithm, continuous optimization of oxygenation and maintenance of adequate anesthetic depth are essential.

Awareness of time between intubation attempts is crucial; unnecessary attempts should be avoided.

Assistance may be summoned at any stage.

Outcome

If oxygenation and ventilation are successfully maintained, the procedure can proceed.

✓ Effective implementation of preoxygenation and apneic oxygenation is of critical importance in pediatric patients.

✓ Team communication should be ensured after each step, and the continuity of oxygenation must be maintained.

✓ All interventions should be performed using age-and weight-appropriate, pediatric-sized equipment.

DAS (DIFFICULT AIRWAY SOCIETY) PEDIATRIC DIFFICULT AIRWAY ALGORITHM[9]

The 2015 DAS guideline and subsequent updates propose a systematic and practical pediatric difficult airway algorithm, distinct from the adult version.

The main goals are the maintenance of oxygenation and rapid transition between sequential steps (Table 12).

Preparation

- An experienced anesthesiologist and a team skilled in airway management should be present and ready.
- All necessary equipment (videolaryngoscope, fiberoptic bronchoscope, SGA, bougie, FONA devices) must be readily available.
- Role allocation within the team should be defined in advance.

Table 12. DAS pediatric difficult airway algorithm

Step	Method/strategy	Explanation
Preparation	Experienced team, monitoring, equipment	
Intubation attempt	Direct or video laryngoscopy	Max. 2 attempts
Failed intubation	Oxygenation via face mask	Two-person technique, airway adjuncts
Failed mask ventilation	Supraglottic airway (SGA)	If oxygenation is achieved, proceed with the intervention
SGA failure / no oxygenation	Emergency surgical airway (needle cricothyrotomy, jet ventilation)	Last resort; surgical approach not recommended under 8 years of age

Intubation Attempt

- Intubation should be attempted using direct or VL; no more than two attempts are recommended.
- If oxygenation is lost or intubation fails, the next step should be initiated immediately.

Mask Oxygenation

- If mask ventilation is unsuccessful, adjunct airway devices, two-person technique, and optimal positioning should be employed.
- If oxygenation can be maintained, the procedure can safely continue.

SGA Placement

- If mask ventilation is not feasible, a supraglottic airway (SGA) device should be inserted immediately.
- If oxygenation is achieved via the SGA, fiberoptic intubation through the device can be attempted if necessary.

FONA (Front of Neck Airway) / Emergency Surgical Airway

- If oxygenation cannot be achieved with SGA, emergency surgical airway (FONA) should be considered.
  - o ≤8 years: Surgical cricothyrotomy is not recommended; needle cricothyrotomy with jet ventilation is preferred.
  - o ≥8 years: Either surgical or needle cricothyrotomy may be performed.

✓ Maintenance of oxygenation is essential at every stage.

✓ In the event of a failed intervention, the next step should be initiated without delay.

✓ Patient safety must be prioritized throughout all phases.

KEY CLINICAL HIGHLIGHTS FROM GUIDELINES

- In pediatric difficult airway algorithms, age, body weight, and compatibility with available equipment are critically important factors.
- The primary goal emphasized in both algorithms is: Ensuring continuous oxygenation and effective airway management without the development of complications.

- At each stage, team communication, cognitive aids (e.g., checklists, color-coded medications), and crisis management should be prioritized.

CONCLUSION

Pediatric airway management is a complex and high-risk process due to unique anatomical and physiological differences, rapid decompensation risk, and evolving equipment and techniques. Contemporary guidelines (ASA, DAS), with their algorithmic approaches and device diversity, enhance applicability in clinical practice. VL, new-generation SGAs, ultrasonography, and simulation-based training have become indispensable components of clinical success supported by experience and up-to-date education. The integration of regularly updated guidelines and technologies enables safe and effective pediatric airway management, leading to improved outcomes.

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The authors have no conflicts of interest to declare.

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