REVIEW ARTICLE

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# Airway management in pediatric patients: an update

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## ABSTRACT

One of the crucial responsibilities of an anesthesiologist is to secure the airway for anesthesia or resuscitative purposes. The patients of pediatric age group differ from adults, both anatomically and physiologically. This is the basic reason that an anesthesiologist has to carefully evaluate and use specific devices and methods to safely manage the airway in pediatric patients. There are various syndromes that pose challenges in children due to distinctive pathology leading to difficult airway. In the present scenario in the field of anesthesia, many gadgets and tools are available that may assist in airway management in pediatrics. Though these devices resemble the ones used in adult age group but specific changes in methods may be employed to overcome the anatomical differences. This article deals with the perfect evaluation of airway as well as specific problems and their solutions in pediatric age group. The advances in simulation technology are quite helpful in providing training in the field of difficult pediatric airway. Following the recommended guidelines and algorithms would go a long way in securing a safe airway in pediatrics.

**Key words:** Pediatric airway; Difficult intubation; Airway, anatomy; Airway, Physiology; Abnormal airway

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## INTRODUCTION

Anesthesiologists have to learn a variety of skills to conduct anesthesia, particularly in the pediatric age group. Securing the pediatric airway is one of the tasks that require skill and dexterity. It is of vital importance that the pediatric anesthesiologist should have in-depth understanding of anatomy and physiology of the pediatric patient, especially the neonate and the infant. In addition, he/she should be familiar with the pathological aspects of pediatric airway. The knowledge of various devices and techniques currently prevalent is a must to manage the airway safely. Fortunately, the incidence of difficult airway is less common in pediatric age group as compared to the adults.[1,2]

Most anesthesiologists are well trained to manage airway in the adult age group but children are not small adults. The methods and procedures required in pediatric patient are not similar, due to developmental differences. If the concerned anesthesiologist is prepared beforehand to manage the difficult airway, better results would follow. The present article underlines the vital dissimilarities in anatomy and physiology of an adult and a child. The congenital pathological conditions that may complicate the pediatric airway are described. The currently available devices, gadgets and procedures to manage airway in pediatrics have been considered in detail. The awareness of basic concepts, current guidelines, as well as, algorithms is vital to minimize complications related to pediatric airway management.[3]

## MANAGEMENT OF PEDIATRIC AIRWAY

It is vital that the skill of managing pediatric airway should be regularly practiced. The recent advances in technology have led to safe and secure management of airway in pediatric age group. Current devices

have made a significant shift in advancement in this field. Though, technology has improved but we must be acquainted with the minute details of pediatric airway to achieve a successful outcome. The ASA Closed Claim Database has provided details regarding advancement in airway management of pediatric population. Till about two decades ago, the main concern was ventilation and oxygenation but the respiratory events have been on the decline in the last few years. In pediatric age group, the incidence of difficult airway that includes difficult ventilation and intubation is 0.25 to 3%, much less than that in adults. ([3]). It has been observed that more than two attempts may lead to unsuccessful intubation or problems like hypoxia or even cardiac arrest.

## ANATOMY OF PEDIATRIC AIRWAY

Securing the airway in pediatric age group is not similar is not similar to adults, as the anatomy differs considerably. The anatomical differences are more pronounced in newborns, neonates and infants. This results in difficulty in visualization of larynx during laryngoscopy.[4] The child's head is relatively larger with a prominent occiput. Facial structures are smaller in size compared to the head size as the paranasal sinuses are absent.[5] When the child is under

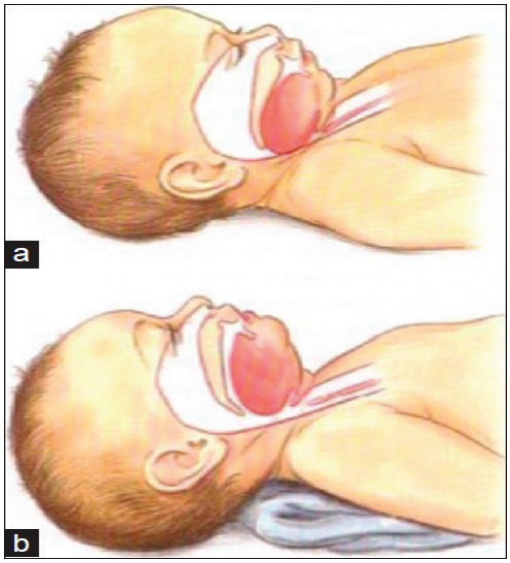


**Figure 1: Prominent occiput causing flexion of neck and airway obstruction with the base of tongue (a) The obstruction disappears after placing a shoulder roll (b) Courtesy: Harless J et al[6]**

anesthesia the airway gets obstructed easily as a result of flexion of neck. If a small pillow is placed under the shoulders, neutral position the neck becomes neutral and the airway obstruction is minimized (Figure 1).[6]

Since the axis of trachea, oral cavity and larynx are not aligned due to larger size of head, occiput and a short neck laryngoscopy in pediatric patients becomes difficult.

In infants and younger children, the size of mandible is smaller and the tongue is relatively larger. For a few months after birth a child breathes through the nose. Around the age of 5 years, a child may develop enlargement of tonsils and adenoids. All these features may lead to difficulty in breathing and ventilation with a face mask, as well as, difficult laryngoscopy. Further obstruction of airway is likely while inducing general anesthesia since various anesthetics may reduce the tone of airway muscles. The hypo pharynx in a child is short and narrow, while the airway of adult is oblique and oval in shape.[7]

The level of larynx is higher in pediatric age group. The level of cricoid ring is at C4 in newborn and at C5 by the age of five years while it is at C6 in an adult.[8] The larynx in neonate is conical in shape while in an older child it is cylindrical. The larynx is slanting in children and not situated at right angle to the trachea. This feature may contribute to difficult intubation.[9]

The insertion of endotracheal tube into the larynx may not be affected but it may face resistance at the level of anterior commissure. The size of the vocal cords is smaller in neonates and forms the anterior half of glottis compared to 2/3rd in older children. The epiglottis is leafy, U-shaped and large, thus obscuring the view of larynx.[10] Till the adolescent age, the larynx and trachea do not become calcified.[11]

In case of negative pressure ventilation, there may be airway obstruction since the tracheal rings are elastic.[12]

Previously it was believed that in children the narrowest part was at the level of cricoid and the airway was funnel shaped, but in recent years, MRIs and bronchoscopy images have revealed that the glottis opening is narrower than that at cricoid level.[13,14] Since the cricoid cartilage is not elastic and distensible, for all practical purposes, it still remains the narrowest part of pediatric airway.

The anteroposterior diameter is larger at cricoid level but the shape of cricoid is elliptical. This affects the choice of using cuffed or uncuffed tube in pediatric patient. The length of trachea depends on height and age and not on the weight of the child.[15,16,17]

## PHYSIOLOGY

The pediatric age group, especially infants and neonates have specific physiological considerations

that may lead to hypoxemia and other consequences. The consumption of oxygen in infants is 6 ml/kg/min as compared to adults (3ml/kg/min) at rest.[18]

Even after preoxygenation, the saturation may deteriorate during induction of anesthesia since FRC in infants is relatively smaller. The preoxygenation also does not provide enough safe period to avert desaturation in case of short duration apnea.[19]

The production of carbon dioxide is raised in infants i.e. 130 mL/kg/min while in adults it is 60 mL/kg/min. To counter this larger production of carbon dioxide and removal, respiratory rate is higher. Since resistance to air flow is inversely proportional to the radius of pediatric airway, decrease in diameter due to inflammation or edema may lead to unwarranted respiratory complications. There are various pathological conditions that may increase the narrowing of pediatric airway. These may be congenital such as tracheomalacia or clefts in larynx or lesions like papilloma's or hemangiomas within the trachea. Also, acquired problems like subglottic stenosis and vocal cord paralysis may add to the airway compression.[20] In these conditions, any edema or inflammation may lead to further airway deterioration.

Laryngospasm may be total or partial. If total there is no chest movement, noise or bag movement. Mask ventilation is also not possible. In partial laryngospasm, chest movement, stridor and bag movement are present. Mask ventilation is possible to some extent.[21] Various risk factors of laryngospasm include recent upper respiratory tract infection, secretions in the airway, and multiple attempts at intubation, upper airway surgery and inexperienced anesthesiologist.[22]

## EVALUATION OF AIRWAY

The outcome of anesthesia in pediatric patients depends on anticipating an airway problem and to plan accordingly. There is no single test for preoperative assessment of pediatric airway which is reliable or unanimously accepted.[23]

Various diagnostic techniques to assess the pediatric airway include MRI and CT scan.

Routine clinical assessment of the airway may not be feasible in pediatric patients since they usually do not cooperate. MRI is superior to CT scan as it uses non-ionizing radiation. Moreover, MRI provides better soft tissue contrast and generates an image through each body-plane. For anesthesia purposes, ultrasound is appropriate to assess airway as it is easily available in modern anesthesia set-up. Though in adults, there are several studies assessing epiglottis, glottis, and cricoid cartilage and tracheal rings using ultrasound, there is scarcity of literature related to pediatric airway. Ultrasound is also helpful in measuring correct tube size as well as accurate placement of tracheal tube but routine practice is yet to be clinically established.[24-26]

In pediatric age group, one must obtain history from parents pertaining to events that may lead to possible airway problems. Any history of difficulty in speech, breathing or feeding is important. If the parents narrate any event of sleep apnea, snoring or day time sleepiness would be informative regarding a difficult airway.

**Congenital syndromes and anomalies related to pediatric airway**:[27]

There are various congenital syndromes that may have impact on management of airway in pediatric patients. In Goldenhar syndrome, cervical problem and micrognathia may complicate the airway. Pierre Robin syndrome is another well-known disorder that comprises of large tongue, cleft palate and micrognathia that may pose a serious situation in laryngoscopy and visualization of larynx. Treacher-Collins syndrome includes small mouth opening, underdeveloped zygoma and micrognathia. All three syndromes described above are related to oropharynx and oral cavity (Table 1). Apert syndrome includes large tongue, limited cervical movements, midface hypoplasia and micrognathia. Klipple-Feil syndrome presents with fusion of cervical spine. Microstomia is the highlight of Hallermann-Streif syndrome. The Down syndrome may pose difficult pediatric airway because of large tongue, small oral cavity and atlanto-occipital disorders.

As in case of adults, evaluation parameters are pertinent and relevant in children, too. Out of numerous factors that predict complex airway; decreased mandibular space, large tongue and restricted extension of head are dependable factors.[28] A few scoring systems have also been described in literature .These are based on facial measurements and correlated to laryngeal view but are clinically not practical. Some of the studies have shown correlation between lip to chin distance and length of mandible with Cormack and Lehane grading of laryngoscopic view of the larynx.[29] Hemifacial microsomia and congenital microtia have

**Table 1: Congenital syndromes related to pediatric airway**

| Site | Congenital Syndromes |
|---|---|
| Oral cavity | Pierre Robin syndrome |
| | Goldenhar syndrome |
| | Treacher Collins syndrome |
| Trachea | Klippel-Feil syndrome |
| Cervical spine | Goldenhar syndrome |
| Mandible/Maxilla | Apert syndrome |

also been associated to difficult laryngeal view in a few studies.[30,31]

There may be an important airway issue in craniopagus twins i.e. the conjoined twins who are fused at the cranium. Incidence of the condition is 10-20 children in every million births. The maintenance of airway in such twins is a challenge in its own way.[32,33]

Some clinical conditions and systemic diseases, such as cardiothoracic surgery, individuals with low BMI, patients with Mallampati class III/IV, ASA grade III and IV and infants have been associated with difficult laryngoscopic view in up to 1.3% cases.34

## TECHNIQUES AND DEVICES FOR PEDIATRIC AIRWAY

An experienced anesthesiologist usually finds no difficulty in securing airway in routine pediatric patients. In some cases, problem in airway management may lead to hypoxemia, cardiac arrest or even mortality.[35,36] In the long-term, the effects of hypoxemia during anesthesia are not well studied and documented.

Classification of pediatric airway problems: The difficulties faced in managing pediatric airway are classified into three categories:

A: Normal (anatomically and physiologically)

B: Impaired Normal (earlier normal airway but presently affected by swelling, trauma, burns etc.)

C. Known Abnormal (due to syndromes and congenital causes).

In straight-forward cases, securing the airway should not be a problem but in difficult airway the approach and strategy should be based on algorithms.[37]

Problems and emergency situations: The basic aim of airway management in children is to ensure oxygenation and ventilation. Adequate ventilation with facemask is the key to the successful airway management and calls for regular practice and training. An experienced anesthetist never has a problem in ventilating a normal child.

Various tools and techniques to manage perioperative pediatric airway may include mask ventilation, oral and nasopharyngeal airways, various laryngoscopes, supraglottic devices, video-laryngoscopes, fiberoptic bronchoscopes and as a last resort surgical airway techniques. There are many options for induction of anesthesia in case there is anticipated difficult airway.

Mask ventilation: The basic skill in management of pediatric airway is adequate ventilation of the child with face mask using one or two hands. In case there is difficulty in mask ventilation following obstruction, it may be overcome by lifting the chin, extending the head, thrusting the jaw forward or using CPAP.[38] Moreover, keeping the child in 'tonsillar position' i.e. left lateral position, lifting the chin and extending the head would help in maintaining the airway.39 Ventilating via face mask may add to the anatomical dead space which is a detrimental factor in infants.40

Problems in mask ventilation may occur when head positioning is not adequate, child is obese or a foreign body is present in upper airway. Other causes may include laryngospasm due to light plane of anesthesia, bronchospasm, over-inflation of stomach and closure of glottis due to opioids. In a difficult situation following an obstruction due to anatomical or functional causes, an easy to remember algorithm should be followed to prevent hypoxemia (Figure 2).

Oral and Nasal airways: The oral airway may be helpful when mask ventilation is undertaken both in spontaneous or controlled ventilation since it helps in preventing the tongue fall. The suitable size of airway may be estimated by measuring the distance from angle of mandible to corner of the mouth.[41] The nasal or nasopharyngeal airways may also be employed when any obstruction to airway occurs while ventilating with a face mask. These airways are also recommended for compromised airway to

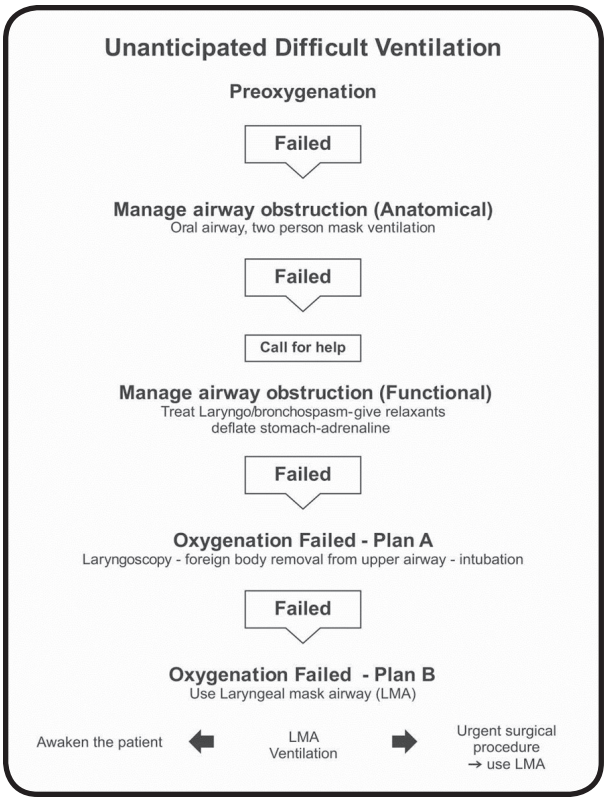


**Figure 2: Unanticipated difficult ventilation algorithm**

insufflate oxygen or monitor EtCO2 while using fiberoptic bronchoscope.[42]

**Supraglottic devices:** These are relatively newer devices to manage airway. There are numerous devices available commercially and each device has indications advantages and disadvantages. Various considerations in using supraglottic devices are seal pressure, aspiration port, single or multiple use and material used for the cuff. Other factors include the learning curve and ability to insert a tracheal tube through the device. In pediatric age group, Classic as well as ProSeal laryngeal mask airway (LMA) have been found to be more useful and safe for ventilation, with success rates up to 98 percent.[43,44] In a large study of 1400 patients, the difficulties and morbidity was as low as 11.5 percent.[45] The ProSeal LMA has been used successfully even in infants in procedures such as laparoscopic surgery.46 In case of upper respiratory infection in pediatric age group, the use of supraglottic devices, have an edge over tracheal intubation. The use of LMA results in less respiratory problems than tracheal intubation. [47] However, the use of LMA may lead to more respiratory complications in children with recent upper respiratory infection when compared with those with no history of such infection.[48] The cuff pressure of LMA should be monitored intraoperatively so that it does not exceed 60 cm$H_2O$. The higher cuff pressure may cause injury to mucosa due to higher perfusion pressure.[49]

It is ideal to keep the intra-cuff pressure around 40 cm$H_2O$ to prevent leak as well as pain in throat in immediate postoperative period. Several newer supraglottic devices, such as Fastrach, air-Q and I-gel are available through which tracheal tube may be directly placed with success rates of more than 95 percent.[50-52]

2.4.6. Endotracheal tubes: The skill of intubating the trachea is part of the basic training of anesthesiologists. The main goal is to avoid hypoxemia and not the intubation of trachea. Hence it is generally advised that it is the ventilation that may save the patient and not the intubation.

Numerous devices have been recommended to secure airway by intubating the trachea. The use of laryngoscope for tracheal intubation is a standard technique and various designs as well as sizes of blades are commercially available. For older pediatric age group, Macintosh laryngoscope is still widely used. The tip of the Macintosh blade is placed in glosso-epiglottic fold and larynx is visualized by lifting the epiglottis indirectly. In younger age group i.e. less than five years old, the epiglottis is relatively larger in size and not in same axis as trachea, it is difficult to lift the epiglottis indirectly. Hence, it is recommended to use the straight blade e.g. Miller blade or semi- curved blade to lift the epiglottis directly to visualize the larynx.[53,54]

In the past, uncuffed tracheal tubes were preferred in infants and younger patients, so to reduce the chances of subglottic trauma. Currently, there is increasing trend to use cuffed tracheal tubes in this age group, as now it is considered that conditions for ventilation are better with cuffed tubes. The frequency of laryngospasm is more with uncuffed tube than the cuffed one.[55] The uncuffed ETT may lead to pressure damage to mucosa in the subglottic area even if the leak pressure is within normal range.[56]

It has been suggested that if the air leak can be heard with airway pressure < 20cm $H_2O$, over-inflation of ETT cuff cannot be avoided. In a study, cuff pressures were found to be 40-60 cm $H_2O$ on an average while it should not exceed 30 cm H2O.[57]

**Induction technique:** When a difficult airway is anticipated, there are numerous anesthetic choices to induce the patient. Though induction with volatile agents has the advantage of spontaneous breathing but in case of increased depth of anesthesia, laryngeal and pharyngeal reflexes are depressed adding to the obstruction of upper airway.

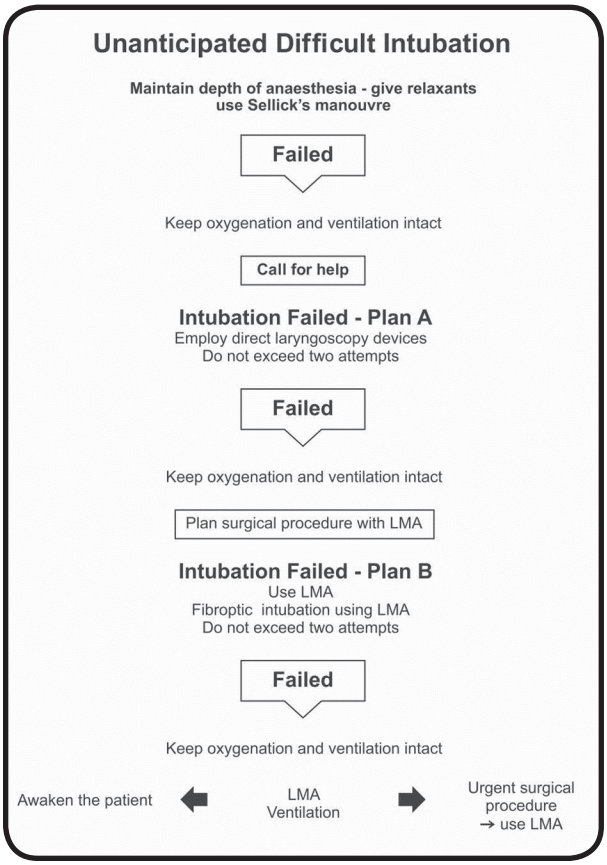


**Figure 3: Unanticipated difficult Intubation algorithm**

A simple and easy to follow algorithm using the best available local facilities should be followed[58] (Figure 3).

Still it is the most popular technique for difficult airway in children as revealed by many surveys.[59] Regarding choice of narcotics, fentanyl and remifentanil are ideal for perfect intubating conditions and are widely preferred. For neuromuscular blockade, the choice of relaxant is between suxamethonium and rocuronium. The latter may be easily reversed with sugammadex though it has the limitation of not reversing other anesthetic agents that have been administered, concurrently.

**Fiberoptic bronchoscope:** For anticipated difficult airway in adult patients awake intubation using fiberoptic bronchoscope is the technique of choice, since it allows longer period of time to intubate, while the patient is breathing spontaneously.[60]

Since cooperation is lacking in pediatric age group the choice of awake intubation is not practical. There are techniques that may be employed using supraglottic devices to achieve fiberoptic intubation. In one technique, supraglottic device is placed and fiberopic is used through an exchange catheter or Aintree. After entry into the trachea, fiberoptic bronchoscope and supraglottic device is removed and exchange catheter or Aintree is left in trachea over which tracheal tube is advanced.[61]

Alternatively, fiberoptic bronchoscope is passed through an already placed supraglottic device to enter trachea. A guide wire is passed through the drug port of the scope and left in trachea. Both fiberscope and supraglottic device are removed and a bougie or exchange catheter is advanced over the wire followed by placement of tracheal tube over the bougie or catheter.[62]

**Video-laryngoscope:** This is a useful device that makes laryngoscopy much easier and successful. Various video-laryngoscopes in the market are C-MAC, King Vision, Glidescope McGrath among others.[63] An improved view of larynx can be achieved when it is difficult or impossible to do so by direct laryngoscopy, as revealed by various trials using the video-laryngoscopes.[64]

A video-laryngoscope cannot replace the practice of standard direct laryngoscopy since they may not be available all the times and may not be suitable for all clinical situations. Efficiency in skill of mask

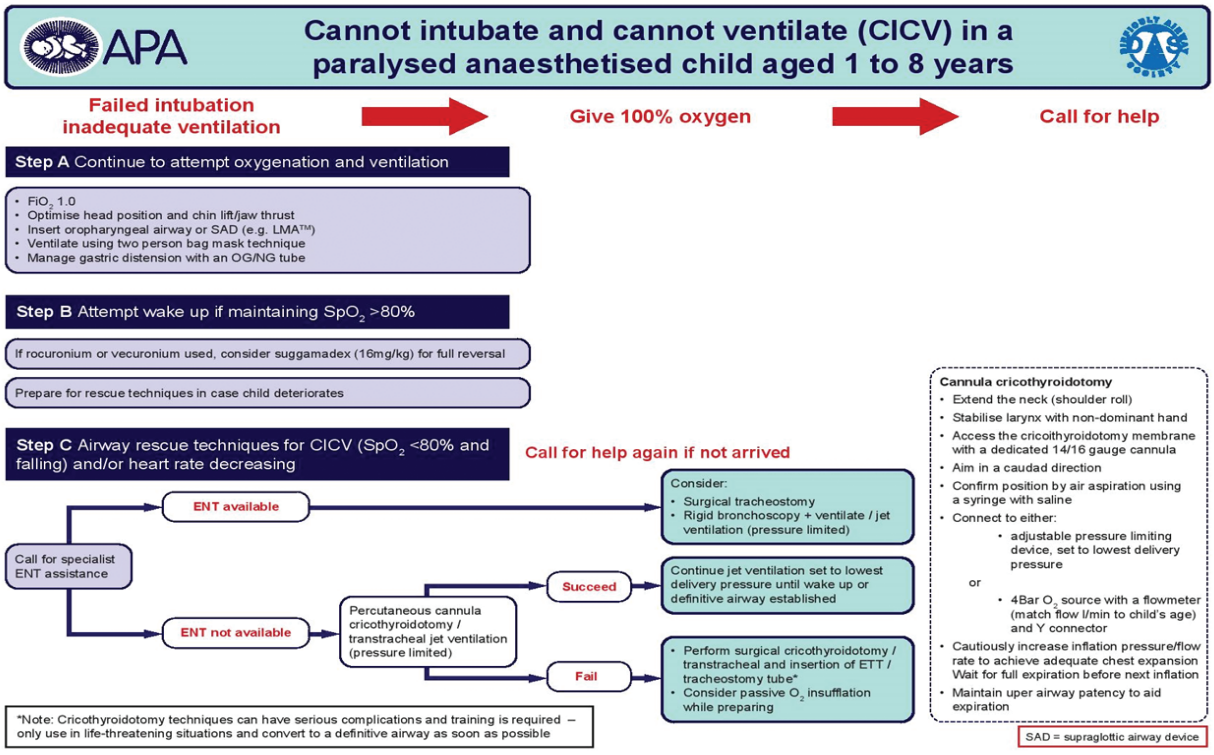


**Figure 4: Reproduced from Difficult Airway Society 2015 guidelines for management of unanticipated difficult intubation in adults. C. Frerk, V. S. Mitchell, A. F. McNarry, C. Mendonca, R. Bhagrath, A. Patel, E. P. O'Sullivan, N. M. Woodall and I. Ahmad, Difficult Airway Society intubation guidelines working group *British Journal of Anesthesia*, 115 (6): 827–848 (2015)**

ventilation and direct laryngoscopy is the basic of pediatric airway management.

**Surgical Airway:** The challenges in management of airway may be either due to inadequate ventilation with face mask or failure to secure airway by tracheal intubation.[[65] These two factors may sometimes lead to the development of "cannot ventilate, cannot intubate" scenario. In 2015, APAGBI Pediatric Difficult Airway have suggested Guidelines for this situation (Figure 4).

In case, oxygen desaturation occurs following both an unsuccessful mask ventilation and tracheal intubation, needle cricothyroidotomy is recommended. This emergency technique may be more difficult in pediatric age group. The needle may cross-puncture the elastic trachea and pierces the esophagus. The hazards of cricothyroidotomy in younger children below 5 years of age are greater than in adults; hence direct surgical cricothyroidotomy is a preferred choice in younger children.[66] On the other hand, it is documented that cricothyroid membrane in neonates is of small, hardly measuring 3 mm in size.[67] Moreover, in infants, laryngeal prominence is not appreciated so it is difficult to detect thyroid cartilage. Therefore, percutaneous puncture between the tracheal cartilages should be preferred to secure emergency airway and ventilation.[68]

**Extubation of pediatric airway:** Extubation in pediatric patients is a risky situation. The decision to extubate the child in deep plane or awake with adequate respiratory efforts lies with the concerned anesthesiologist. In case the intubation was difficult, it is recommended to extubate when the child is fully awake, respiratory efforts are adequate and airway reflexes are appropriate. Some anesthesiologists are in favour of extubation in deep plane of anesthesia to minimise the extubation response but it may be associated with respiratory complications.[69] In case the child has undergone surgery in prone position; the extubation should be done more carefully so as to avoid accidental extubation.[70]

**Rapid Sequence Induction in pediatric patients**

There has been a controversy regarding Rapid Sequence Induction and intubation (RSII) in pediatric age group. It is established that RSI prevents regurgitation and aspiration in patients with full stomach. This includes preoxygenation for a few minutes followed by administration of hypnotic agent and depolarising muscle relaxant accompanied by Sellick's manoeuvre or application of cricoid pressure.[71] At the same time, problems associated with RSI such as hypoxia, difficult intubation and bradycardia have to considered.[72] The concept of "Controlled rapid sequence induction and intubation (cRSII) has been advocated which includes administration of hypnotic agent followed by nondepolarising muscle relaxant.[73] A gentle mask ventilation is carried out without the use of Sellick's manoeuvre. This study by Neuhaus et al using cRSII involving over one thousand children found no hazardous conditions for tracheal intubation while administering general anesthesia in full stomach pediatric patients. The contraindications of administering succinylcholine in RSII still remain the same i.e. children with muscular disorders.

## CONCLUSION

One of the major responsibilities and expertise an anesthesiologist should possess is the successful management of airway, particularly in pediatric age group. There are considerable differences in airway management in children when compared to those in adults. The anesthesiologist should have thorough understanding of anatomy, physiology and various congenital and complicating syndromes before making a successful strategy for securing a pediatric airway. With thorough knowledge of basic concepts, proper use of various devices and suitable algorithms, the hypoxemia in children can be avoided perioperatively. In the past few years, there has been considerable evolution in pediatric airway. There has been a significant change in anesthesia training in this age group. The cricoid ring that was believed to be the narrowest part of pediatric airway is less likely as shown by the recent studies. Further research is needed to assess the airway in pediatric population. Through, regular practice and training, morbidity and mortality related to pediatric airway can be significantly minimized.

**Conflict of interest:** The authors declare no conflict of interest involved.

**Authors' contribution:** Both authors contributed equally in preparation of this manuscript

## REFERENCES


1. Kheterpal S, Han R, Tremper KK, Shanks A, Tait AR, O'Reilly M, et al. Incidence and predictors of difficult and impossible mask ventilation. Anesthesiology. 2006 Nov;105(5):885-91. [PubMed]
2. Tait AR, Voepel-Lewis T, Burke C, Kostrzewa A, Lewis I. Incidence and risk factors for perioperative adverse respiratory events in children who are obese. Anesthesiology. 2008 Mar;108(3):375-80. [PubMed] DOI: 10.1097/ALN.0b013e318164ca9b
3. Khan ZH. An infant's airway: a difficult terrain. Saudi J Anaesth. 2016;10:253-4. [PubMed] DOI: 10.4103/1658-354X.174905
4. Asadollah M, Soltani A E, Abtahi M. Evaluation of laryngoscopic views and related influencing factors in a pediatric population. Paediatr Anaesth. 2011;21(6):663-7. [PubMed] DOI: 10.1111/j.1460-9592.2011.03555.x
5. Shariffuddin I, Chan C. The paediatric airway: normal and abnormal. In: Khan ZH, editor. Airway Management. 1st ed. Switzerland: Springer;2014. p. 81-92.
6. Harless J, Ramaiah R, Bhananker SM. Pediatric airway management. Int Crit Illn Inj Sci. 201;4(1):65-70. [PubMed] DOI: 10.4103/2229-5151.128015
7. Schendel SA, Jacobson R, Khalessi S. Airway growth and development: a computerized 3-dimensional analysis. J Oral Maxillofac Surg. 2012 Sep;70(9):2174-83. [PubMed] DOI: 10.1016/j.joms.2011.10.013
8. Dalal PG, Murray D, Messner AH, Feng A, McAllister J, Molter D. Pediatric laryngeal dimensions: an age-based analysis. Anesth Analg. 2009;108(5):1475-9. [PubMed] DOI: 10.1213/ane.0b013e31819d1d99
9. Gooden CK. An Update on pediatric airway management. Int Anesthesiol Clin. 2017;55(1):86–96. [PubMed] DOI: 10.1097/AIA.0000000000000132
10. Adewale L. Anatomy and assessment of the pediatric airway. Paediatr Anaesth. 2009;19 (Suppl1):1–8. [PubMed] DOI: 10.1111/j.1460-9592.2009.03012.x
11. Rifkin MD, Pritzker HA. Tracheobronchial cartilage calcification in children. case reports and review of the literature.Br J Radiol. 1984 Apr;57(676):293-6. [PubMed] DOI: 10.1259/0007-1285-57-676-293
12. Mortensen A, Lenz K, Abildstrom H, Lauritsen TL. Anesthetizing the obese child. Paediatr Anaesth. 2011;21:623–9. [PubMed] DOI: 10.1111/j.1460-9592.2011.03559.x
13. Dalal PG, Murray D, Feng A, Molter D, McAllister J. Upper airway dimensions in children using rigid video-bronchoscopy and a computer software: description of a measurement technique. Paediatr Anaesth. 2008;18:645-53. [PubMed] DOI: 10.1111/j.1460-9592.2008.02533.x
14. Litman RS, Weissend EE, Shibata D, Westesson PL. Developmental changes of laryngeal dimensions in unparalyzed, sedated children. Anesthesiology. 2003;98:41–5. [PubMed]
15. Hunyady AI, Pieters B, Johnston TA, Jonmarker C. Front teeth-to-carina distance in children undergoing cardiac catheterization. Anesthesiology. 2008;108(6):1004-8. [PubMed] DOI: 10.1097/ALN.0b013e3181730288
16. Weiss M, Balmer C, Dullenkopf A, Knirsch W, Gerber AC, Bauersfeld U, et al. Intubation depth markings allow an improved positioning of endotracheal tubes in children. Can J Anaesth. 2005;52(7):721–6. [PubMed]
17. Weiss M, Gerber AC, Dullenkopf A. Appropriate placement of intubation depth marks in a new cuffed paediatric tracheal tube. Br J Anaesth. 2005;94:80–7. [PubMed] DOI: 10.1093/bja/aeh294
18. Philippi-HöhneC. Anaesthesia in the obese child. Best Pract Res Clin Anaesthesiol. 2011 Mar;25(1):53-60. [PubMed]
19. Hardman JG, Wills JS. The development of hypoxaemia during apnoea in children: a computational modelling investigation. Br J Anaesth. 2006;97(4):564-70. [PubMed] DOI: 10.1093/bja/ael178
20. Bruce IA, Rothera MP. Upper airway obstruction in children. Paediatr Anaesth. 2009;19(Suppl 1):88-99. [PubMed] DOI: 10.1111/j.1460-9592.2009.03005.x
21. Hampson-Evans D, Morgan P, Farrar M. Pediatric laryngospasm. Paediatr Anaesth. 2008;18:303–7. [PubMed] DOI: 10.1111/j.1460-9592.2008.02446.x
22. Al-alami AA, Zestos MM, Baraka AS. Pediatric laryngospasm: prevention and treatment. Curr Opin Anaesthesiol. 2009 Jun;22(3):388-95. [PubMed]
23. Khan ZH. Airway assessment: a critical appraisal. In: Khan ZH, editor. Airway Management, 1st ed. Switzerland: Springer;2014. p. 15-32.
24. Marciniak B, Fayoux P, Hebrard A, Krivosic-Horber R, Engelhardt T, Bissonnette B. Airway management in children: ultrasonography assessment of tracheal intubation in real time? Anesth Analg. 2009;108:461–5. [PubMed] DOI: 10.1213/ane.0b013e31819240f5
25. Schramm C, Knop J, Jensen K, Plaschke K. Role of ultrasound compared to age-related formulas for uncuffed endotracheal intubation in a pediatric population. Paediatr Anaesth. 2012;22(8):781–6. [PubMed] DOI: 10.1111/j.1460-9592.2012.03889.x
26. Shibasaki M, Nakajima Y, Ishii S. Shimizu F, Shime N, Sessler DI. Prediction of pediatric endotracheal tube size by ultrasonography. Anesthesiology. 2010;113(4):819–24. [PubMed] DOI: 10.1097/ALN.0b013e3181ef6757
27. Nargozian C. The airway in patients with craniofacial abnormalities. Paediatr Anaesth. 2004;14(1):53-9. [PubMed]
28. Akpek EA, Mutlu H, Kayhan Z. Difficult intubation in pediatric cardiac anesthesia. J Cardiothorac Vasc Anesth. 2004 Oct;18(5):610-2. [PubMed]
29. Sunder RA, Haile DT, Farrell PT, Sharma A. Pediatric airway management: current practices and future directions. Paediatr Anaesth. 2012 Oct;22(10):1008-15. [PubMed] DOI: 10.1111/pan.12013
30. Nargozian C, Ririe DG, Bennun RD, Mulliken JB. Hemifacial microsomia: anatomical prediction of difficult intubation. Paediatr Anaesth. 1999;9(5):393-8. [PubMed]
31. Uezono S, Holzman RS, Goto T, Nakata Y, Nagata S, Morita S. Prediction of difficult airway in school-aged patients with microtia. Paediatr Anaesth. 2001;11:409–13. [PubMed]
32. Khan ZH, Tabatabai S, Saberi H. Anesthetic and surgical experience in a case of total vertical craniopagus. Surg Neurol. 1999;52:62-7. [PubMed]

33. Khan ZH, Hamidi S, Miri SM. Craniopagus, Laleh and Laden twins, sagittal sinus. Turkish Neurosurg. 2007;17(1):27-32. [PubMed]
34. Heinrich S, Birkholz T, Ihmsen H, Irouschek A, Ackermann A, Schmidt J. Incidence and predictors of difficult laryngoscopy in 11,219 pediatric anesthesia procedures. Paediatr Anaesth. 2012;22(8):729-36. [PubMed] DOI: 10.1111/j.1460-9592.2012.03813.x
35. de Graaff JC, Bijker JB, Kappen TH , van Wolfswinkel L, Zuithoff NP, Kalkman CJ. Incidence of intraoperative hypoxemia in children in relation to age. Anesth Analg. 2013;117(1):169–75. [PubMed] DOI: 10.1213/ANE.0b013e31829332b5
36. Bhananker SM, Ramamoorthy C, Geiduschek JM, Posner KL, Domino KB, Haberkern CM, et al. Anesthesia-related cardiac arrest in children: update from the Pediatric Perioperative Cardiac Arrest Registry. Anesth Analg. 2007;105(2):344–50. [PubMed] DOI: 10.1213/01.ane.0000268712.00756.dd
37. Weiss M, Engelhardt T. Proposal for the management of the unexpected difficult pediatric airway. Paediatr Anaesth. 2010;20(5):454–64. [PubMed] DOI: 10.1111/j.1460-9592.2010.03284.x
38. Meier S, Geiduschek J, Paganoni R, Fuehrmeyer F, Reber A. The effect of chin lift, jaw thrust, and continuous positive airway pressure on the size of the glottic opening and on stridor score in anesthetized, spontaneously breathing children. Anesth Analg. 2002;94(3):494-9. [PubMed]
39. Arai YC, Fukunaga K, Hirota S, Fujimoto S. The effects of chin lift and jaw thrust while in the lateral position on stridor score in anesthetized children with adenotonsillar hypertrophy. Anesth Analg. 2004;99(6):1638-41. [PubMed] DOI: 10.1213/01.ANE.0000135637.95853.1C
40. Brambrink AM, Braun U. Airway management in infants and children. Best Pract Res Clin Anaesthesiol. 2005;19(4):675-97. [PubMed]
41. Baker PA, Navaratnarajah J, Black AE. Assessment and management of the predicted difficult airway in babies and children. Anaesth Intens Care Med. 2015;16(12):622-31.
42. Holm-Knudsen R, Eriksen K, Rasmussen LS. Using a nasopharyngeal airway during fiberoptic intubation in small children with a difficult airway. Paediatr Anaesth. 2005;15(10):839–45. [PubMed] DOI: 10.1111/j.1460-9592.2004.01566.x
43. Goyal R. Small is the new big: an overview of newer supraglottic airways for children. J Anaesthesiol Clin Pharmacol. 2015 Oct-Dec;31(4):440–9. [PubMed] DOI: 10.4103/0970-9185.169048
44. Mason DG, Bingham RM. The laryngeal mask airway in children. Anaesthesia. 1990;45(9):760–3. [PubMed]
45. Lopez-Gil M, Brimacombe J, Alvarez M. Safety and efficacy of the laryngeal mask airway. a prospective survey of 1400 children. Anaesthesia. 1996 Oct;51(10):969-72. [PubMed]
46. Sinha A, Sharma B, Sood J. ProSeal as an alternative to endotracheal intubation in pediatric laparoscopy. Paediatr Anaesth. 2007;17(4):327-32. [PubMed] DOI: 10.1111/j.1460-9592.2006.02127.x
47. Tait AR, Pandit UA, Voepel-Lewis T, Munro HM, Malviya S. Use of the laryngeal mask airway in children with upper respiratory tract infections: a comparison with endotracheal intubation. Anesth Analg.1998;86(4):706–11. [PubMed]
48. Yu SH, Beirne OR. Laryngeal mask airways have a lower risk of airway complications compared with endotracheal intubation: a systematic review. J Oral Maxillofac Surg. 2010 Oct;68(10):2359-76. [PubMed] DOI: 10.1016/j.joms.2010.04.017
49. Licina A, Chambers NA, Hullett B, Erb TO, von Ungern-Sternberg BS. Lower cuff pressures improve the seal of pediatric laryngeal mask airways. Paediatr Anaesth. 2008 Oct;18(10):952-6. [PubMed] DOI: 10.1111/j.1460-9592.2008.02706.x
50. Jagannathan N, Sohn LE, Sawardekar A, Gordon J, Shah RD, Mukherji II, et al. A randomized trial comparing the Ambu® Aura-i™ with the air-Q™ intubating laryngeal airway as conduits for tracheal intubation in children. Paediatr Anaesth. 2012;22(12):1197-204. [PubMed] DOI: 10.1111/pan.12024
51. Malhotra SK, Bharath KV, Saini V. Comparison of success rate of intubation through Air-Q with ILMA using two different endotracheal tubes. Indian J Anaesth. 2016;60(4):242-7. [PubMed] DOI: 10.4103/0019-5049.179448
52. Barch B, Rastatter J, Jagannathan N. Difficult pediatric airway management using the intubating laryngeal airway. Int J Pediatr Otorhinolaryngol. 2012;76(11):1579-82. [PubMed] DOI: 10.1016/j.ijporl.2012.07.016
53. Santillanes G, Gausche-Hill M. Pediatric airway management. Emerg Med Clin North Am. 2008;26(4):961-75. [PubMed] DOI: 10.1016/j.emc.2008.08.004
54. Doherty JS, Froom SR, Gildersleve CD. Pediatric laryngoscopes and intubation aids old and new. Paediatr Anaesth. 2009;19(Suppl 1):30–7. [PubMed] DOI: 10.1111/j.1460-9592.2009.03001.x
55. von Ungern-Sternberg BS, Boda K, Chambers NA, Rebmann C, Johnson C, Sly PD, et al. Risk assessment for respiratory complications in paediatric anaesthesia: a prospective cohort study. Lancet. 2010;376(9743):773–83. [PubMed] DOI: 10.1016/S0140-6736(10)61193-2
56. Schmidt AR , Weiss M, Engelhardt T. The paediatric airway: basic principles and current developments. . Eur J Anaesthesiol. 2014 Jun;31(6):293-9. [PubMed] DOI: 10.1097/EJA.0000000000000023
57. Ong M, Chambers NA, Hullet B, Erb TO, von Ungern-Sternberg BS. Laryngeal mask airway and tracheal tube cuff pressures in children: are clinical endpoints valuable for guiding inflation? Anaesthesia. 2008;63(7):738–44. [PubMed] DOI: 10.1111/j.1365-2044.2008.05486.x
58. Mathru M, Esch O, LangJ, Herbert ME, Chaljub G, Goodacre B, et al. Magnetic resonance imaging of the upper airway; effects of propofol anesthesia and nasal continuous positive airway pressure in humans. Anesthesiology. 1996;84(2):273–9. [PubMed]
59. Brooks P, Ree R, Rosen D, Ansermino M. Canadian pediatric anesthesiologists prefer inhalational anesthesia to manage difficult airways. Can J Anaesth. 2005;52(3):285–90. [PubMed]
60. Sims C, von Ungern-Sternberg BS. The normal and the challenging pediatric airway. Paediatr Anaesth. 2012;22(6):521–6. [PubMed] DOI: 10.1111/j.1460-9592.2012.03858.x
61. Choi EK, Kim JE, Soh SR, Kim CK, Park WK. Usefulness of a Cook airway exchange catheter in laryngeal mask airway-guided fiberoptic intubation in a neonate with Pierre Robin syndrome - a case report. Korean J Anesthesiol. 2013 Feb;64(2):168-71. [PubMed] DOI: 10.4097/kjae.2013.64.2.168
62. Walker RW. The laryngeal mask air-

way in the difficult paediatric airway: an assessment of positioning and use in fibreoptic intubation. Paediatr Anaesth. 2000;10(1):53-8. [PubMed]
63. Baker PA, Brunette KE, Byrnes CA, Thompson JM. A prospective randomized trial comparing supraglottic airways for flexible bronchoscopy in children. Paediatr Anaesth. 2010 Sep;20(9):831-8. [PubMed] DOI: 10.1111/j.1460-9592.2010.03362.x
64. Nagler J, Bachur RG. Advanced airway management. Curr Opin Pediatr. 2009;21(3):299–305. [PubMed] DOI: 10.1097/MOP.0b013e32832b112c
65. Malhotra S K. Surgical approaches to airway management. In: Khan ZH, editor. Airway Management. 1st ed. Switzerland: Springer; 2014. p. 223-38.
66. Engelhardt T, Weiss M. A child with a difficult airway: what I do next? Curr Opin Anaesthesiol. 2012;25(3):326-32. [PubMed] DOI: 10.1097/ACO.0b013e3283532ac4
67. Coté CJ, Hartnick CJ. Pediatric transtracheal and cricothyrotomy airway devices for emergency use: which are appropriate for infants and children? Paediatr Anaesth. 2009;19(Suppl 1):66–76. [PubMed] DOI: 10.1111/j.1460-9592.2009.02996.x
68. Navsa N, Tossel G, Boon JM. Dimensions of the neonatal cricothyroid membrane - how feasible is a surgical cricothyroidotomy? Paediatr Aanesth. 2005;15(5):402-6. [PubMed] DOI: 10.1111/j.1460-9592.2005.01470.x
69. Tsui B C H, Wagner A, Cave D, Elliott C, El-Hakim H, and Malherbe S. Incidence of laryngospasm with a 'no touch' extubation tectnique after Tonsillectomy and adenoidectomy. Anesth Analg. 2004;98(2):327–9. [PubMed]
70. Malhotra SK, Nakra D. Temperature probe in distal esophagus: a cause of accidental extubation in an infant. Paediatr Anaesth. 2006 Oct;16(10):1098-9. [PubMed] DOI: 10.1111/j.1460-9592.2006.01964.x
71. Bledsoe G, Schexnayder S. Pediatric rapid sequence intubation: a review. Pediatr Emerg Care. 2004;20(5):339–44. [PubMed]
72. Gencorelli FJ, Fields RG, Litman RS. Complications during rapid sequence induction of general anesthesia in children: a benchmark study. Paediatr Anaesth. 2010;20(5):421–4. [PubMed] DOI: 10.1111/j.1460-9592.2010.03287.x
73. Neuhaus D, Schmitz A, Gerber A, Weiss M. Controlled rapid sequence induction and intubation—an analysis of 1001 children. Paediatr Anaesth. 2013;23(8):734–40. [PubMed] DOI: 10.1111/pan.12213

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# HONORS & AWARDS

## RICHARD 'HARRY' HARRIS AND CRAIG CHALLEN HONORED

Cave rescue divers Australian Anesthetist Richard 'Harry' Harris and his colleague Craig Challen have both been named 2019 Australian of the Year for their heroic efforts in saving 12 boys from a flooded cave in Thailand. "Richard Harris and Craig Challen led a heroic rescue under the spotlight of the world's media. They placed the safety of others above their own and inspired hope when hope seemed lost,"

Dr Harris's medical expertise was instrumental in the plan to safely evacuate the children.

After swimming through the narrow cave system to assess the health of those trapped and giving the medical all-clear for each child, he administered an anesthetic to each to enable their rescue and remained underground until the last evacuee was safe.

Dr Challen's technical expertise was critical to the rescue and he worked 10 to 12 hours each day in perilous conditions to swim the children one-at-a-time through the dark and narrow flooded caves.

The pair had been about to leave for a cave-diving holiday when they received the call for help with the delicate rescue mission.