Review Article

Airway in the newborn patient

Abstract

Expertise in neonatal airway management requires an understanding of early human anatomical development as well as set of clinical skills to provide safe mask ventilation and tracheal intubation in the extremely small-sized population of patients. Although problematic management of the pediatric airway including difficulties with mask ventilation or unsuccessful endotracheal intubation remains rare, it is one of the primary causes of perioperative morbidity and mortality.

Airway management is key component in various clinical scenarios, including the operating room during the provision of anesthetic care, in the pediatric intensive care unit, in the emergency department or during resuscitative efforts. This article is divided into three sections, anatomy and fisiology of the neonatal upper airway. Standard neonatal airway management and algorithms for managing the anatomically abnormal neonatal airway.

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Introduction

Understanding the airway in a newborn patient is a priority, in view of the anatomical and physiological unique characteristics which they have that don't repeat themselves through a person's life: they only last the first years of a person's life. These characteristics are necessary for understanding and manipulating the normal or complicated airway. Newborns usually require urgent surgeries, many of them premature with low birth weight and hemodynamically unstable. The correct manipulation of the airway is fundamental in every newborn. Problems during airway manipulation in the newborn are an important cause of morbidity, oxygen desaturation and secondary hypoxia. They cause the most frequent complication in the pediatric population, and are inversely proportional to the child's age. When the gestation weeks are fewer and the weight is lower, it is more complicated to manipulate the airway.

Problems during tracheal intubation and airway manipulation are more common in children less than a year old, since they consume more oxygen and have lower oxygen reserves, which make tolerance to apnea minimal. Hypoxia leads to severe bradycardia. The incidence of airway complications in this age group is 0.6%, which lowers to 0.1% in preschool children and 0.05% in children older than 8 years. The newborn includes full term and preterm children, both of them different they present a series of situations to consider when manipulating the airway. Finally it is important to mention a particular hemodynamic state which is called transition circulation, which is intermediate between the fetal and adult circulation. It persists for four months until the definitive closure of the ductus arteriosus, the oval foramen and the decrease of lung resistance are established permanently, which give the newborn special characteristics.

Upper airway anatomy

This part will only refer to the anatomical and physiological differences that are important to airway manipulation in the newborn and infant. The anatomical differences can be divided in six parts: the skull, the tongue, the pharynx, the larynx, the trachea and the thoracic box. The skull shape is more elongated which makes the occiput more prominent, meaning that the occipital portion is relatively long; this characteristic leads to a flexion of the head axis over the neck axis, mainly when the newborn is in a supine position. Occurs an alteration of the airway axes, in consequence and it can obstruct the airway easily, for this reason children need a small bundle under the shoulders to achieve the sniffing position and guarantee airway permeability.

When establishing a relation over the size of the tongue and the oral cavity, there is a larger proportion in tongue size, making it seem as though the tongue doesn't fit in the small oral cavity. Under anesthetic conditions and in the supine position the tongue moves backwards and comes into contact with the pharynx, which limits the free passage of air. The larynx also differs in its support, its resistance to collapse and position, but not in shape. The hyoid bone is the main support for the muscles that hold the tongue and larynx in its resting position and only the central part of the hyoid bone is ossified, the rest is cartilage. This is why, when using direct laryngoscopy, the traction force applied over the base of the tongue doesn't affect the hyoid bone, doesn't modify the larynx and doesn't help in the visualization of the glottis. The newborn airway is more vulnerable to collapse during inspiration of deglutition. Another important aspect of the larynx is that it is more cephalic, C3-C4, descending in the adult to its position in C4-C5. The epiglottis is longer and thinner, having an omega shape and not the inverse U that is observed in the adult patient. This explains why it's easier to perform direct laryngoscopy using Miller blades (or straight) blades.

Because in vivo studies such as nuclear magnetic resonance, flexible fibrobronchoscopy, ultrasound and other studies, today we know that the narrowest part of the airway, until 4 or 5 years of age, is the transverse diameter at the local chords or immediately under them and their functional morphology is more cylindrical, with an elliptic and not circular disposition. However the vocal chords are flexible and can therefore expand the glottis when introducing the tracheal tube, while the diameter of the cricoid ring is fixed. This explains why lesions after extubation are localized in the vocal chords as well as the subglottic region.

The indications to placing a tube with an air-filled cuff have been motive for discussion, and have changed in the last years, now being preferred to place a tube with a cuff since birth, considering the respiratory advantages and its safety. In the neonatal intensive care unit these advantages turn more evident, where children use mechanical ventilation for several days, for example, there is a lower leakage of oxygen, accidental extubation has a lower incidence, and oxygenation and ventilation are better. The trachea longitude is also smaller, in the newborn it is around 4 cm, and in the premature newborn even smaller.

The internal diameter of the trachea is about 7 mm for children 1 to 4 years of age. In the preterm newborn the diameter is 2 – 4 mm, while in children 4 to 8 years old it is 8 mm. the smaller the tracheal diameter represents a higher vulnerability to the conditions that decrease the diameter the airway, such as hyperreactivity, inflammation or any damage produced by the insertion of endotracheal tubes and the airway instrumentation. The insistence in the number of attempts to intubate a newborn or infant produces inflammatory processes with faster and more intense responses, which decrease the caliber of the trachea and diminish the passage of oxygen. This is the reason why only two attempts are now considered as a maximum.

It is very important to measure the distance at which the tracheal tube is fixed in respect to the labial commissure. Otherwise we could intubate only one bronchi, generally the right one. One of the multiple forms to calculate the depth of the endotracheal tube, is to calculate 3 times the internal diameter of the tube used. For example, if we use an endotracheal tube number 4, its distance will be 12 cm. The newborn has a short neck, making the newborn seem as though the head is over its shoulders. They also have a physiological hypoplasia jaw, resulting in a smaller oral cavity, small pharyngeal space and a small mouth, anatomical aspects that contribute to the difficult airway in the newborn.

The thoracic box differs in form and function, the structures that conform them are cartilaginous. The ribs have a more horizontal disposition, the epigastric angle is obtuse and the abdominal organs are relatively larger. The residual functional capacity is smaller comparedtoits large alveolar volume, which means they can't tolerate long periods of apnea and rapidly develop hypoxia. From a cardiovascular point of view, they present an increased vagal tone, with a tendency to bradycardia during laryngoscopy or tracheal intubation.[1]

Difficult airway predictors in the newborn

Until now there isn't a scale that allows us to predict with certainty the degree of difficulty to intubate or ventilate a newborn, such as there aren't for other ages besides newborn patients. There are currently a number of difficult airway predictors, but their sensitivity and specificity vary in clinical practice. The predictor with good performance are mandibular protrusion. Movement of atlantooccipital joint, reduced mandibular space, and increased tongue thickness. The thyromental distance can be used for difficult airway prediction too.

Difficult airway should be anticipated in several congenital syndromes, the presence of one or several congenital syndromes of systemic diseases that involve the airway are more important than the predictors used in adults. Inspection alone and general appearance of a patient can suggest problems for intubation or ventilation. Many of the craniofacial syndromes involve a complex airway, the jaw size, its relation to the face, micrognatia or hypoplasia of a maxillary, prognathism, mouth aperture, tongue size, nostril permeability, cervical spine flexion and extension, the presence of a tumor or abscess in the neck, stridor, rhonchus, sialorrhea, sleeping positions, oral breathing, etc. (Pierre Robin, Apart syndrome, Hunter and Hurlet syndrome, Backwith-Wiedermann syndrome, Freeman-Sheldon syndrome, Down syndrome, Klippel-Fail syndrome, Hallermann-Streiff syndrome, Arthrogryposis, Cri-du-chat syndrome, Edwards syndrome, and fibrodysplasia ossificans progressive).

The airway evaluation needs to include the patient´s medical history: birth complications, history of trauma, previous surgery, airway management during previous anesthesia, physical examination, and current pathology which can determine in the newborn.[2] When the newborn cries or is being fed, we can evaluate oral aperture, tongue size, vellopalatine coordination, and in general airway permeability. These situations should be considered a priority when getting a patient's background. Besides the physical characteristics already described, there is another situation which can alert anesthesiologists to a difficult airway which is the presence of abnormalities of implantation of the ear canal. Some authors have tried to establish this anomaly as a parameter for difficult airway. See table for most frequent morphological syndromes in the newborn (Tables 1&2). Unexpected difficult face mask ventilation in children varies from 2.8 to 6.6% and the incidence of difficult endotracheal intubation varies between 0.06% and 1.34%.[3]

Technique for permeating the newborn airway

The first technique is for children under 3 years old. A small bundle shall be placed beneath the shoulder blades to compensate the modification in the axes that is caused by the large occiput in the newborn, while in children older than 3 years old, the bundle is placed under the occiput. Ventilation, using a face mask, allows us to ventilate and oxygenate the newborn in a less invasive way. If we wish to apply positive pressure, then the face mask should offer a hermetic seal with the face, meaning it should be the right size, soft and cushy on the edges to avoid leaks, and avoiding pressure on the eyes. The most accepted face masks are transparent to observe lip color and the presence of secretions such as saliva, vomit or foreign objects. The face mask should be placed over the nose and the chin, decreasing the anatomic dual space. It should be held with three fingers, placing them under the patient's jaw, while a slight upward and forward movement is made. This manoeuver separates the tongue from the posterior wall of the pharynx, and eases ventilation. Fingers in the dominant hand 3, 4, and 5, form the letter E, and fingers 1 and 2 form the letter C. In most newborns the facial mask is enough to apply a peak inspiratory pressure under 15 cm H_2O and a respiratory rate of 20 – 40 per minute.[4]

During the inhalational induction of anesthesia, there is a progressive decrease in muscle tone with loss of the normal function or the genioglossus muscle and the musculature of the oropharynx. During this time, the tongue may fall into the posterior pharynx, leading to upper airway obstruction. Reestablishment of a patent airway is generally feasible by maintaining a tight mask fit with an open mouth and maneuvers to keep the tongue off the roof of the mouth. Although these are generally corrected by repositioning or placement of an oral or nasal airway. An oral airway that is too large or that is placed during a light plane of anesthesia can stimulate cough, emesis, and laryngospasm. The most common cause of unexpected loss of gas exchange and hypoxemia during anesthetic induction is laryngospasm.

They ease ventilation with face masks, correcting the rhonchus created by the partial obstruction caused by the tongue. These devices are indicated for anesthesia with inhaled induction. Nasopharyngeal airways are left for situations where there is jaw trauma of anatomical alterations that don't allow the mouth to open. The ideal size for the oral airway is determined by placing them on the side of the face, with the distal end in angle with the temporomandibular joint, and the proximal end with the lip commissure. The essential technique for maintaining an airway open in newborns is subluxation of the temporomandibular joint, which is achieved by placing the 5th finger in the retromandibular notch, immediately beneath the external ear canal and behind the pinna.

Tracheal intubation and direct laryngoscopy

The correct position for tracheal intubation has already been discussed and varies with age. Direct laryngoscopy is the most common method for tracheal intubation. The classic "sniffing" position is not the best way to intubate a patient, since with this position we displace the larynx even higher. The neutral position allows a better alignment of the laryngeal, pharyngeal and oral axes. The Miller blade is the right one for this group of patients, since besides better alignment of the oral and laryngeal axes, it offers better control and displacement of the base of the tongue. It's important to use the BURP (back up right pressure) manoeuver, which allows a better visualization for the vocal chords.

The Miller blades are small according to the size of the mouth, it's a reduced blade. The blade is introduced in the right mouth commissure and moves to the left to displace the tongue as much as possible. The tip of the blade allows us to touch the epiglottis and elevate the structure for better larynx visibility.

Endotracheal tubes with and without air cuffs

Traditionally, tracheal tubes in the newborn have been selected without an inflating cuff, because of possible harm to the subglottic region. This was derived from the concept that the narrowest point in the airway is the cricoid cartilage. Historically the uncuffed tracheal tubes were used in pediatric patients under 8 years, and to minimize possible oedema formation due to cuff caused mucosal damage. Nevertheless today that concept has changed because there are new discoveries of the airway. Today we know that the airway is more elliptic than circular, and that the narrowest point is at the level of the vocal chords, even though these are flexible when introducing the tracheal tube and can therefore increase the glottis diameter. A higher incidence of laryngospasm with the use of uncuffed tubes has also been reported. The size of tracheal tubes remains age-related. For cuffed tubes Cole´s formula results can be used, reduced by 0.5 or 1.0 mm.

Tracheal tubes have also been modified structurally, and today we have low-pressure high-volume tubes that haven't been associated to damage (respiratory croup) post-extubation. The incidence of airway damage is the same with or without an air cuff. On the contrary, tubes with air cuff have allowed less pollution in the operating room because of a better seal. One of the largest advantages of cuffed tubes is that they significantly reduce the exchange rate (from 25% to 2%). No increase in morbidity has been reported with the lasted cuffed tracheal tubes use in pediatric intensive care unit patients. It's important to mention that the critical pressure at which newborn tracheal blood flow is interrupted is not well known, hence pressures no larger than 20 mmHg are recommended. The tube should be checked before its insertion, sterile and transparent polyvinyl, with a radiopaque line so that it's visible in x-rays. Generally they have marks in centimeters to determine the distance at which it will be fixed and its internal or distal extreme has a pair of black lines that help as a reference to localize the vocal chords and avoid overinsertion of the tube.[5,6]

Remember not to overinflate the air cuff and exceed the stated pressure, and to always monitor the pressure periodically or deinflate and inflate again every 2 hours. Tubes with an air cuff decrease the incidence of associated extubation, they lead to a better mechanical ventilation, improve a patient oxygenation and prevents bronchoaspiration. It's more harmful to place a larger tube because it can damage the tracheal mucosa and cause edema, ischemia or subglottic stenosis. Always remember that nitrous oxide increases the cuff pressure. There are many formulas to estimate the size of the tube, but for the first 2 years of life there is no exact formula and the sizes should always be remembered (Table 3).

Airway management algorithm

It's a series of organized steps that show the process that we should follow to solve a determined problem. There are multiple algorithms in the world's literature for a same problem. One of the most widely known algorithms is the one from the American Society of Anesthesiology (ASA) 2013 which helped define difficult airway. It defines it with a clinical situation in which a conventionally trained anesthesiologist experiences difficulty with face mask ventilation of the upper airway, difficulty with tracheal intubation, or both. This definition requires us to explain difficulty in ventilation, which can be defined as the impossibility to maintain a SaO2 of at least 92% with a FiO2 of 1.0, or an important gas leak around the mask, or the necessity to maintain a fresh gas flow of 15 L/min, or using flush in the machine to maintain ventilation, or the necessity to ventilate with both hands, or changing operator.

Finally, difficult intubation is defined as that which can't be accomplished after two attempts under expert hands. Its incidence is fortunately low, and is approximately 5–35/10,000. The Canadian Anesthesiologists Society defines difficult airway when no portion of the vocal chords can be visualized under direct laryngoscopy, intubation requires more than one attempt, it's necessary to switch blades, a new laryngoscopy by another expert, or the use of additional devices for ventilation.[7] Nevertheless we adopt the Echeverry´s algorithm as it's an algorithm proposed by Latin's for similar populations.

Airway in children can be classified in three well defined categories, which also apply to NB: unexpected, suspicious, and anticipated. The most common and disastrous cases happen with unexpected airways. The problems of the unexpected airway present themselves acutely, requiring an immediate solution as a practical guide to be applied in each hospital center (it presents the highest morbimortality by anesthesia (Figure 1).
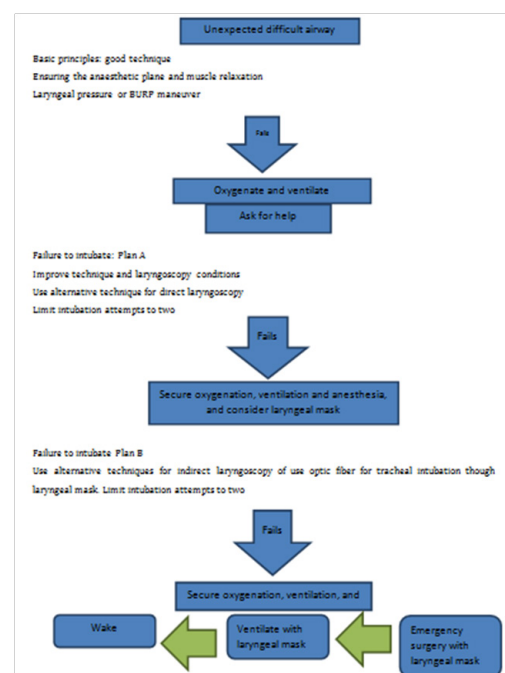

Figure 1 Algorithm for unexpected difficult airway in children.

Table 1 More frequent morphological syndromes in the newborn. Difficult ventilation with a face mask

Maxillar hypoplasia	Choanal atresia
Crouzon syndrome	Marhall syndrome
Apert syndrome	Rubinstein-Taybi syndrome
Pfeiffer syndrome	

Table 2 Possible difficulty during laryngoscopy/intubation

Micrognatia	Possible micrognatia	Macroglosia	Intraoral/Tracheal pathology	Other defects
Pierre Robin sequence	Arthrogryposis, trisomy 8	Beckwith-Wiedemann	Micristomy	Cervical spine complete limitation
Stickler syndrome	Trisomy 9	Congenital hypothyroidism	Congenital temporomandibular dysfunction	Arthrogryposis
Smith-Lemli-Opitz syndrome	Trisomy 13 (Patau)	Down syndrome	Tracheal stenosis	Emery-Dreiffus muscular dystrophy
Treacher-Collins	Trisomy 18 (Edward)	Cystic hygroma	Laryngeal cyst	Others
First arch syndrome	Cornelia Lange syndrome	Mucopolysaccharidosis	Tracheal stenosis	
	Shrpintzen syndrome	Trisomy 4p		
	Freeman-Sheldon syndrome	Weaver syndrome		

Table 3 Formulas to estimate the size of the traqueal tube

Age	Size in mm (Internal diameter)
Preterm newborn (< 1000 g)	2.5
Preterm newborn (1000 – 2500 g)	3
Full term newborn until 6 months	3.0 – 3.5
1 – 2 years	4 – 4.5
>2 years	(age +16)/4 or age/4 + 4

For the management of an unexpected airway and when presented with situations when it's difficult to place a tracheal tube, the recommendation is to use a laryngeal mask or any other supraglottic device to solve the obstruction, ventilate and oxygenate. Clinical experience suggests that placing a laryngeal mask in the newborn is not more difficult than in later weeks of gestation. The laryngeal mask is the most used supraglottic device in neonatal resuscitation when face mask and self-inflating bags have failed. Second generation laryngeal masks allow aspiration of gastric content through a gastric drainage and the oropharyngeal seal is much safer for prevention of bronchoaspiration than with a traditional laryngeal mask, allowing for a safer ventilation.[8] There are also 3rd generation laryngeal masks, which are devices that don't have an air/filled cuff, they maintain pressure on their own. They're self-pressure like the LM Air Q-SP, as the pressure in the airway increases during positive-pressure ventilation of PEEP use, the cuff pressurizes simultaneously improving the seal. Another characteristic of this laryngeal mask is that it can be used as an intubation aid.[9] There are currently published guidelines and reviews that summarize the recommendations in clinical situations of difficult mask ventilation, difficult tracheal intubation, and the cannot intubate cannot ventilated scenario in pediatric population.

We have to remember that when presented with those complex situations of tracheal intubation after two intubation attempts, the priority is not placing a tracheal tube, it's oxygenating the newborn and to ensure its survival (Figure 1). In the case of grade III or IV laryngospasm, a muscle relaxant is required, especially in the presence of severe hypoxia, bradycardia, or eminent cardiovascular collapse. Treatment starts correcting basic maneuvers, such as correcting the patient's position to open the airway, using an oropharyngeal airway and using the 4-hand technique with two persons. Preoxygenating with 100% oxygen helps. If tracheal tube intubation is not possible, use a supraglottic device. It's possible that afterwards a tracheal tube may be placed through the laryngeal mask or with fibrobronchoscopy, which constitutes plan B.[10]

A suspicious airway is more difficult to manage, since it requires experience in the field of pediatric anesthesia. It's usually caused by inflammation of the airways, trauma, foreign bodies, or allergies. These are all common in emergencies, where kids have respiratory infections but still require surgery. They have a high risk for laryngospasm with acute obstruction and ventilator failure, although there aren't anatomical alterations they should be treated as a difficult airway.[11]

In the anticipated airway there are evident malformations that compromise the airway and generally they are congenital more than acquired (trauma, surgeries, burns, tumors, etc). These should be managed in specialized centers with the technology and trained personnel to solve emergencies during difficult airway, they are the highest challenge a pediatric anesthesiologist has. In the management of the suspicious and anticipated airway, contrary to adults, you require a good anesthetic plane under general anesthesia, to minimize cardiovascular and neurological complications. Inhaled agents allow patients to preserve spontaneous breathing. Nevertheless there are conflicting data on the role of muscle relaxants in the case of expected difficult airway in children. Flexible fiberscopic intubation can be performed directly, using the special designed face mask or supraglottic device as a conduit for flexible intubation.

Currently there are no guidelines on how to proceed in this scenario and the majority of anesthesiologists attempt to preserve the patient's spontaneous ventilation during the period of airway securing. Access to a surgical airway like percutaneous cricothyrotomy is only indicated in children over 8 years old, when the airway structures are considered the same as adults and the probability of airway damage or the creation of a false route is less likely. Needle cricothyrotomy is indicated as long as there is a catheter that can be connected to a mechanical ventilation system, giving us 1 to 2 hours to solve the problem in a definitive way. Needle cricothyrotomy allows us to place jet ventilation, which is not always available.[12]

Video laryngoscopes

The bronchoscope with flexible fiber optic remains the gold standard for managing the newborn airway, allowing the aspiration of secretions which other devices don't allow, and the neonatal size has been introduced to improve the effectivity in the management of the airway. With the flexible bronchoscope a neonatal tube of up to 3 mm internal diameter can be passed, nasally and orally. The correct position of some 3rd generation laryngeal masks helps with tracheal intubation and allows simultaneous oxygenation. The nasal airway is another alternative to tracheal intubation. The placing of a flexible bronchoscope requires sedation of the newborn, especially with sevoflurane allowing us to maintain spontaneous ventilation. A special laryngeal mask with bronchoscope access may be used. If placed through the nostrils, a previous application of a vasoconstrictor like oxymetazoline is required to decrease the risk of bleeding. The fibrobronchoscope is not an instrument for a rescue intubation of extreme urgency.[13]

Cricothyroidotomy

Cricothyroidotmy is not recommended in children under 6 years old, owing to the higher incidence of complications in this group of patients, except for needle cricothyroidotomy. Subcutaneous emphysema, neck hematoma, vocal chords lesions, tracheal lesion, cartilage rings rupture, pneumothorax, airway granulomas, subglottic stenosis, and loss of the airway are a few of these complications.[14]

Laryngeal tube

The laryngeal tube is an airway that substitutes the Combitube, available in different sizes for all pediatric population. It has two entrance holes, the first is to ventilate the patient and the second or inferior is to place a gastric tube to aspirate secretions. It has two inflatable cuffs of high volume and low pressure, the proximal one is bigger for the supraglottic region and the other distal is smaller to occlude the esophagus entrance. Between the two cuffs there is a ventilation hole through which the air passes. The laryngeal tube may be placed in the ER by ambulance personnel, mainly to rescue the airway. The laryngeal tube number 0 is the right one for the newborn. This tube should be in all the birth and neonatal surgery rooms. For newborns that are born with asphyxia that can't be ventilated or intubated with conventional laryngoscopy, the quickest way to correct the severe hypoxia is with the laryngeal tube.[15] Finally the airway management should be planned and the anesthesiologist should have a back-up plan for the scenario. The majority of difficult airway in children can be predicted. Finally the airway management should be planned and the anesthesiologist should have a back-up plan for the scenario. The majority of difficult airway in children can be predicted.

Acknowledgments

Conflicts of interest

Funding

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