Continuing Medical Education Article

Airway obstruction in infants and children

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Airway obstruction occurs in infants and children with previously unsuspected airway problems and in those with known conditions (Figure 1). The management of these infants and children is usually successful due to expertise in time-honoured conventional intubation techniques and recent advances in flexible fibreoptic endoscopy. This paper reviews the pathophysiology and symptomatology of infants and children with airway obstruction and presents an algorithmic approach to management.

Pathophysiology

Airway obstruction in a child can be an insidious process until a rapid catastrophic conclusion occurs. Therefore, all symptoms of airway obstruction (stridor, intercostal and substernal retractions, and tachypnoea) are considered serious and demand continuous observation. The narrowest portion of a newborn infant's airway, the cricoid ring, is about 5 mm in diameter.[1] A reduction in the airway diameter requires that the pressure to produce a given flow be increased according to the following equation for turbulent flow:[2]

$$\Delta P \propto \frac{LQ}{r^5}$$

where P is the pressure drop along a tube, L is the length, r is the radius and Q is the flow. Since turbulent flow varies with the fifth power of the radius, a 50 per cent decrease in airway radius will increase the pressure (and work) required to maintain breathing by 32 times. For instance, if r is decreased from 1 to $\frac{1}{2}$, then

$$\Delta P \propto \frac{LQ}{(\frac{1}{2})^5}, \Delta P \propto LQ(2)^5, \text{ and } \Delta P \propto 32LQ.$$

Since tissues of the infant are softer and more compressible than in the adult, attempts to increase negative intrathoracic pressure in the presence of a variable extrathoracic obstruction may cause chest wall retraction, additional stridor and airway collapse.

Complete obstruction

Complete extrathoracic airway obstruction, not responsive to the Heimlich manoeuvre[3] or to the airway clearing manoeuvres suggested by the American Heart Association Guidelines for paediatric CPR[4] (head tilt, chin lift, mouth-to-mouth respiration, back blows and sternal compression), is a true medical emergency and requires immediate establishment of an artificial airway (Figure 2). If tracheal intubation is unavailable or unsuccessful, cricothyrotomy or tracheostomy must be performed.

Incomplete airway obstruction

Congenital laryngeal anomalies

LARYNGOMALACIA

This is the most commonly occurring congenital laryngeal anomaly[5] and is characterized by a long narrow epiglottis and floppy aryepiglottic folds. Although stridor is typically present from birth, it may first appear after weeks or months, and may appear only with crying or in the

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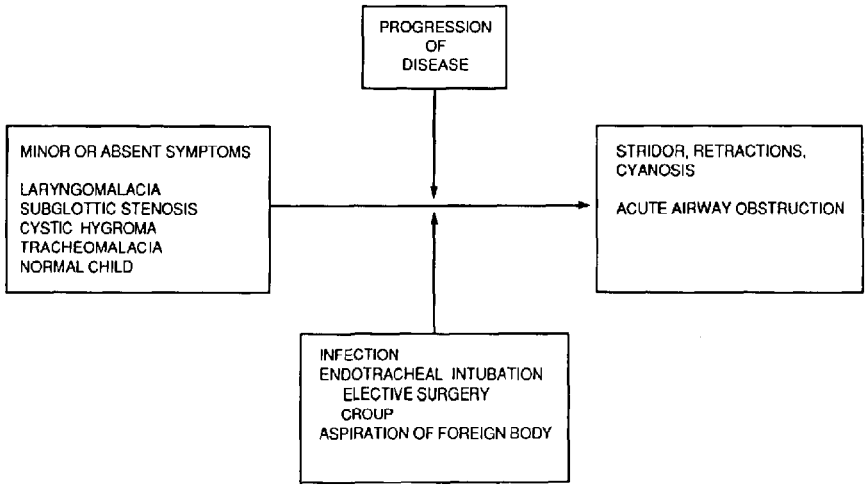

FIGURE 1 The pathogenesis of airway obstruction in infants and children.

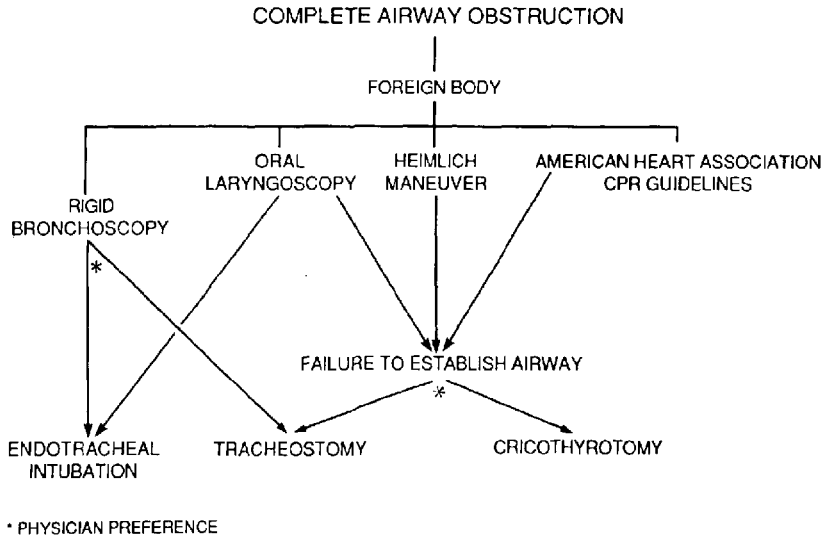

FIGURE 2 An approach to the management of complete airway obstruction in infants and children.

presence of an acute upper respiratory infection. The stridor is of a fluttering nature and is often mistaken for secretions in the hypopharynx. It is usually loudest when the child is supine. Diagnosis is made at laryngoscopy or bronchoscopy. The prognosis is usually excellent and airway intervention is necessary only if acute obstruction develops secondary to precipitating factors (Figure 1). If severe recurrent stridor or cyanosis occurs during feedings, tracheostomy may be necessary.

VOCAL CORD PARALYSIS

Vocal cord paralysis is the second most common laryngeal anomaly found in the newborn period.[5] Bilateral vocal cord paralysis is usually associated with Arnold–Chiari malformation and leads to a severely compromised airway.[6] Presenting symptoms consist of severe inspiratory stridor, cyanosis and respiratory distress in a newborn with a good cry and signs of raised intracranial pressure. Endotracheal intubation followed by tracheostomy is recommended. Laryngoscopy is diagnostic and is performed carefully without anaesthesia. The tip of the laryngoscope blade is placed in the vallecular in order to minimize distortion and immobilization of the vocal cords.[7]

SUBGLOTTIC STENOSIS

Congenital subglottic stenosis is the third most common congenital disorder of the airway in neonates.[5] Furthermore, many premature infants who have been intubated develop acquired subglottic stenosis. In the congenital form, stridor is uncommon at birth but appears within the first few years of life, usually after difficult or unsuccessful extubation attempts in infants who have been intubated for "croup" or elective surgery. Since maximal narrowing occurs just below the cricoid cartilage, slight inflammation can lead to abrupt obstruction.

The treatment of infant subglottic stenosis should be expectant unless acute obstruction occurs. If it does, a nasotracheal tube with an audible air leak at 25–30 cm H_2O pressure is inserted and hydrocortisone 4 $mg \cdot kg^{-1} \cdot day^{-1}$ I.V. is begun. After 48 hours, extubation is attempted followed by racemic epinephrine treatment (see section on "croup" for guidelines). If extubation attempts are unsuccessful and the child is less than one year of age, a surgical division of the cricoid cartilage may be necessary.

LARYNGEAL HAEMANGIOMA

This vascular tumour, which occurs most often in the subglottic region, presents in the first few weeks of life as progressive biphasic (inspiratory/expirator) stridor which increases with crying and venous congestion.[8] The haemangioma enlarges to 90 per cent of its full size by three months of age and then spontaneously regresses by 12–18 months. Although the diagnosis is usually made during bronchoscopy, the presence of a cutaneous haemangioma in an infant with stridor is suggestive of a laryngeal lesion. Treatment includes tracheostomy, prednisone (60 $mg \cdot kg^{-1} \cdot day^{-1}$ PO) and/or CO_2 laser photocoagulation.

ANOMALIES OF THE AORTIC ARCH SYSTEM

Aortic arch anomalies which may produce airway obstruction in infants are: (1) aberrant brachiocephalic artery, (2) aberrant left common carotid artery, (3) right aortic arch with a patent ductus or ligamentum arteriosum, (4) aberrant right pulmonary artery, or, (5) double aortic arch. Infants with vascular compression of the airway present in the head-extended position with wheezing, cough, inspiratory stridor, and a history of repeated respiratory infections, aspiration pneumonia and dysphagia. Although a negative barium oesophagram (when a vascular ring is present) may be misleading (85 per cent in one series),[9] chext *x*-ray, barium oesophagography, and bronchoscopy will usually provide a diagnosis. Diminution of the right radial pulse monitored by a doppler flowmeter during rigid bronchoscopy confirms the diagnosis. Arteriography is necessary to define the vessels prior to surgical repair.

CYSTIC HYGROMA

The multiple sacculated lymphatic ducts associated with this condition can cause oedema of the supraglottic structures and chronic airway obstruction. Acute airway obstruction can occur immediately after birth, or later, if the cystic hygroma proliferates or becomes infected. Infants who are obstructed at birth require immediate orotracheal intubation which is accomplished easily due to the absence of lingular oedema. By contrast, older children who become obstructed frequently have massively enlarged tongues.

LARYNGEAL WEBS, ATRESIA, CYSTS AND LARYNGOCELES

Laryngeal webs, atresia, cysts, and laryngoceles are uncommon causes of airway obstruction in infants.[3] Smaller webs may cause only intermittent hoarseness, whereas larger webs may produce stridor, a weak high-pitched voice, and feeding difficulties (supraglottic webs) or dyspnoea and cough (subglottic webs). Treatment usually consists of CO_2 laser endoscopic lysis.

Infectious airway conditions

Epiglottitis and laryngotracheobronchitis (croup) account for more than 80 per cent of upper airway obstruction in early childhood.[10]

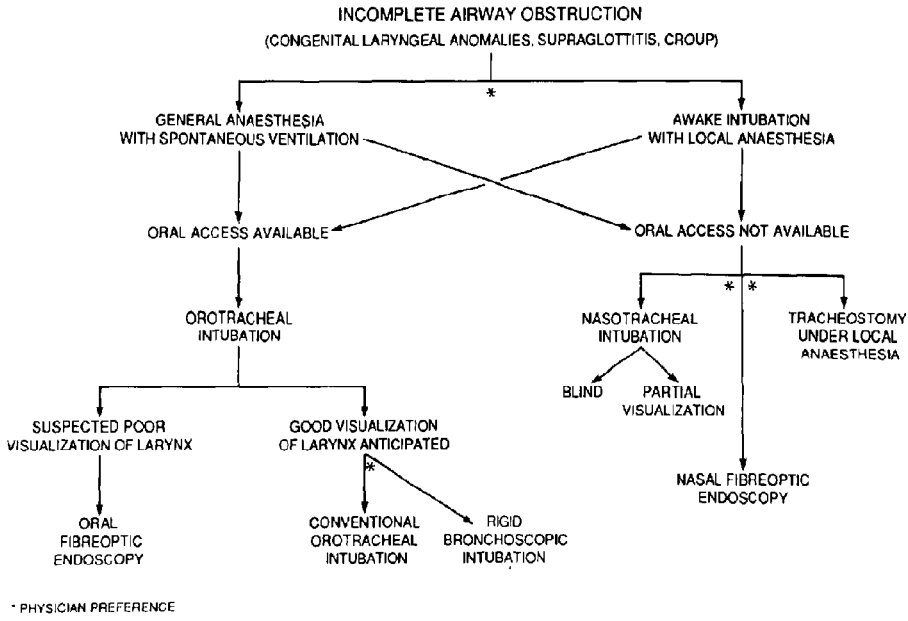

FIGURE 3 An approach to the management in infants and children of incomplete airway obstruction caused by congenital laryngeal anomalies and infectious disease.

Epiglottitis

Epiglottitis characteristically has a dangerously rapid onset of sore throat, high fever, muffled voice, inspiratory stridor, pain on swallowing with both solids and liquids, and respiratory distress. Cough and stridor are not prominent symptoms. The disease primarily affects children two to six years of age but can occur as early as five months as well as in older children and adults. Although the classic picture in epiglottitis is that of a pale, shocky, restless, drooling child in the "tripod" position with the head forward and tongue out, these signs are not always present.[11] Therefore, there must be a high index of suspicion for epiglottitis in the child with fever, sore throat and even mild respiratory distress. Retractions and cyanosis indicate an advanced degree of obstruction. Tachycardia out of proportion to the fever indicates hypoxia. Respiratory arrest may occur spontaneously as a natural course of the disease, or, it may be provoked by laryngoscopy, placing the child supine, venapuncture, arterial puncture for blood gases, or during positioning for radiographic procedures. Since lateral neck and chest *x*-rays are unreliable and may be inaccurate in the diagnosis of epiglottitis (and croup),[12] and since the child is normally removed from the Emergency Room (ER) or Intensive Care Unit (ICU), we feel that such radiographic procedures are rarely indicated. However, if the diagnosis is in question and if adequate *x*-ray facilities are present in the ER or ICU (e.g., "roof-mounted" *x*-ray units) it may be prudent to obtain *x*-rays. If the diagnosis of epiglottitis is in doubt, direct visualization of the larynx is diagnostic and can be made during laryngoscopy in the operating room.

Since sudden deterioration may occur in children with epiglottitis, early airway intervention is required. In a review of 738 cases from 19 studies of children with epiglottitis, there was a higher mortality rate after medical treatment (6.1 per cent) than after intubation (0.92 per cent) or tracheostomy (0.80 per cent).[13] Despite nearly equal mortality rates, nasotracheal intubation is favoured over tracheostomy due to fewer complications and shorter hospital stay associated with the former.[14] Nasotracheal intubation is accomplished in the spontaneously ventilating child who has been anaesthetized with a volatile anaesthesic agent (Figure 3). If the child is in severe respiratory distress, awake rigid bronchoscopy and endotracheal intubation or tracheostomy may be indicated.

In a survey of ten years' experience at our institution, 145 children with epiglottitis and no prior airway manage-

ment were treated.[15] Of these 145 children, 117 were intubated nasally, one was intubated orally, four had tracheostomy and 23 were treated medically (antibiotics, humidified O_2, intravenous fluids, observation and no intubation). Each of the treatment modalities were associated with only minor morbidity and no mortality. However, since epiglottitis is a potentially lethal disease which may deteriorate rapidly, and, since there is minimal morbidity associated with a 12–24 hour period of endotracheal intubation, we recommend early nasotracheal intubation or tracheostomy in all children in which the diagnosis is strongly suspected or confirmed.

Laryngotracheobronchitis (croup)

Laryngotracheobronchitis is an oedematous inflammatory process in the glottic and subglottic regions which usually occurs in children under three years of age who present with crowing inspiratory stridor and a seal-like barking cough after a prodromal upper respiratory illness.

In contrast to epiglottitis, most infants with croup can be managed at home. Hospitalization (in an intensive care unit) is required if the child has harsh inspiratory breath sounds, inspiratory stridor, hoarse cry, nasal flaring, suprasternal retractions and cyanosis in room air.[16] Mild to moderate obstruction can be treated with nebulized racemic epinephrine delivered by face mask and ACORN nebulizer. The solution is prepared by diluting 2.25 per cent racemic epinephrine with sterile water to make 2 ml of a dilution appropriate for the patient's weight in kilograms (1:8 for <5 kg, 1:6 for 5–10 kg, 1:4 for 10–15 kg and 1:3 for 10–20 kg).[17] Nasotracheal intubation is indicated if the child develops delayed inspiratory breath sounds (breath sounds which lag behind chest movements), inspiratory and expiratory stridor, barking cough, and subcostal and intercostal retractions.[16] Nasotracheal intubation in children with croup is not associated with significant subglottic stenosis.[13]

Traumatic airway obstruction

Internal trauma (foreign body aspirations)

Airway obstruction secondary to foreign body aspiration can be intrinsic (laryngeal, tracheal) or extrinsic (oesophageal, Figure 4). The aspiration of foreign bodies is the leading cause of death in the home in children less than six years of age.[18] Aspiration of a foreign body occurs most frequently in one- to three-year-old toddlers who lack molars for breaking up the most commonly aspirated objects: peanuts, seeds, popcorn kernels and carrots.[19]

INTRINSIC FOREIGN BODY (LARYNGEAL, TRACHEAL)

Since foreign bodies lodge in the distal airway 85 per cent of the time, a latent period may elapse before the child becomes symptomatic. Children with distal airway foreign body are more likely to present with wheezing, coughing, and decreased air entry and exhibit obstructive emphysema, atelectasis, or pneumonia on chext *x*-ray. In contrast, children with laryngotracheal foreign bodies present with stridor, dysphasia, dyspnoea, and a normal chext *x*-ray. Although plain *x*-rays of the neck are usually inconclusive due to the radiolucency of most laryngotracheal foreign bodies, impacted subglottic foreign bodies may be diagnosed using rapid spot films of the upper airway.[20]

Emergency or elective removal depends on the severity of respiratory distress. An obtunded child should receive 100 per cent oxygen and is taken directly to the operating room for awake laryngoscopy, endotracheal intubation or bronchoscopy (Figure 5). If the child has a full stomach, and is not in respiratory distress, one may wait four to six hours to decrease the risk of aspiration. If the child has a full stomach and *is* in mild to moderate respiratory distress, bronchoscopy should be performed without delay.

General anaesthesia with spontaneous ventilation is referred for bronchoscopy since this technique maintains the airway, avoids short-acting muscle relaxants and positive pressure ventilation, provides optimal conditions for the bronchoscopist, and allows detection of the conversion from partial to complete airway obstruction (Figure 5). The induction of anaesthesia with intravenous agents and succinylcholine is not recommended. The major risk of intravenous induction with muscle relaxation and positive pressure ventilation is that the foreign body may be pushed further into the airway where it may be less accessible, may create a ball-valve obstruction, or may obstruct both bronchii.

The bronchoscopist should always be present at the induction of anaesthesia. During the foreign body removal, deep anaesthesia is maintained with halothane and oxygen. Succinylcholine must be immediately available in the event that vocal cord relaxation becomes necessary to facilitate removal of a large foreign body or to be used as a measure of last resort if laryngospasm occurs. Atropine 0.02 $mg \cdot kg^{-1}$ IV is included in the premedication to dry secretions and because administration of intravenous succinylcholine may be necessary.

EXTRINSIC FOREIGN BODY (OESOPHAGEAL)

Anaesthesia for the removal of a foreign body in the oesophagus depends on the contour of the object swallowed (Figure 5). If the foreign body has a smooth contour, rapid sequence induction with cricoid pressure and orotracheal intubation is preferred. However, if the foreign body is sharp or jagged, general anaesthesia (in the lateral head down position if stomach is full) with

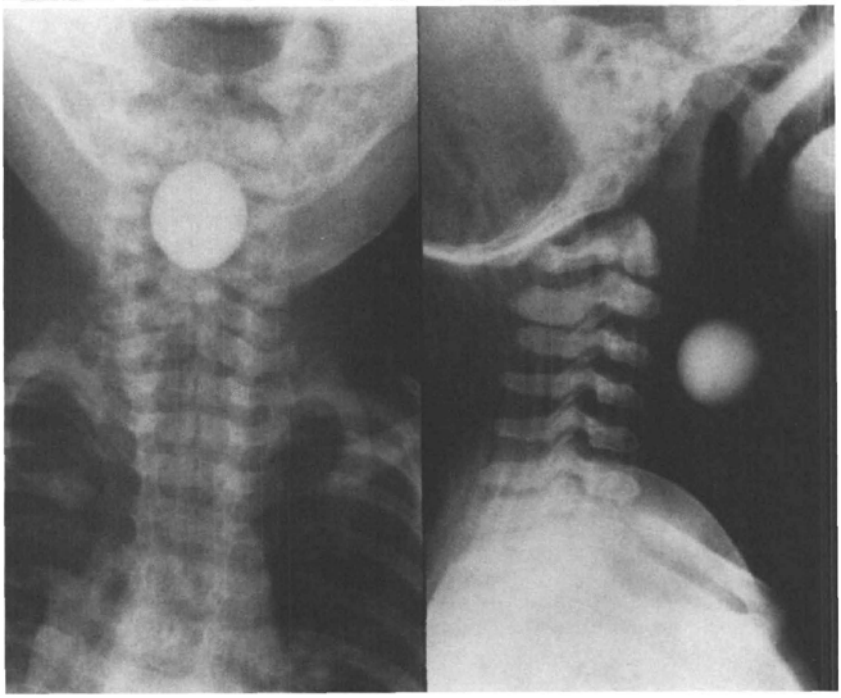

FIGURE 4 Anterior-posterior and lateral radiographs of an 18-month-old infant who had swallowed a marble. The presence of this oesophageal foreign body caused acute airway obstruction by causing extrinsic compression of the trachea.

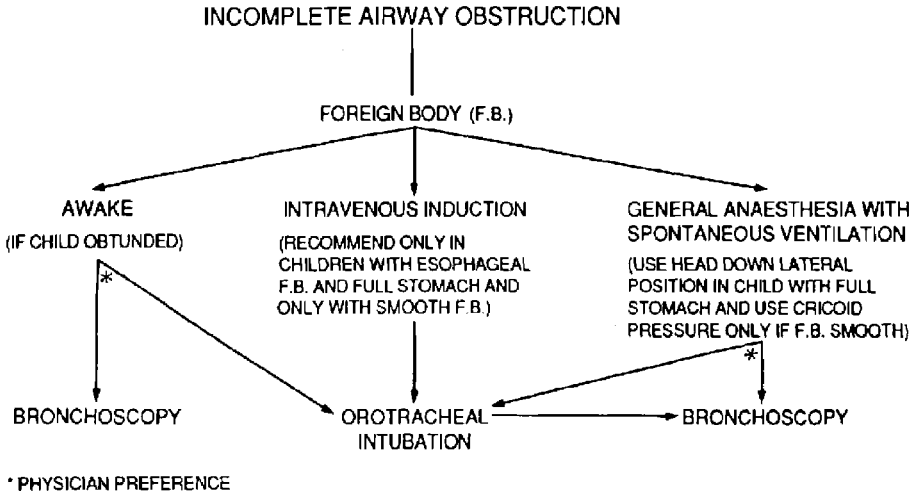

FIGURE 5 An approach to the management in infants and children of incomplete airway obstruction caused by aspiration of a foreign body.

spontaneous ventilation *without* cricoid pressure is preferred.

External trauma (cricothyroid separation)
Although protected from fracture by its pliability, the paediatric larynx can sustain cricothyroid separation.[21] Since external damage may be minimal, cricoid separation is suspected in the injured child who presents with dysphonia dysphagia, stridor, haemoptysis and/or subcutaneous emphysema. Evaluation of the child includes cervical *x*-rays (soft tissue and spine), chest *x*-ray, barium swallow and CT scan of the neck. Since cervical spine injury may be present, laryngoscopy is performed in the neutral position. If the vocal cords and subglottic area are visualized during laryngoscopy, awake oral or nasal endotracheal or rigid bronchoscopic intubation is performed. If the vocal cords and subglottis are obscure, tracheostomy is performed. Blind endotracheal intubation is contraindicated.

Techniques for establishing an airway

The available techniques for establishing an airway in infants and children are:

1 awake orotracheal intubation
2 awake blind or laryngoscopic nasotracheal intubation
3 general anaesthesia with spontaneous ventilation followed by oro- or nasotracheal intubation
4 flexible fibreoptic endoscopic intubation
5 rigid bronchoscopic intubation
6 rapid sequence intravenous induction with cricoid pressure and intubation
7 tracheostomy or cricothyrotomy.

Topical anaesthesia of the airway may be used with techniques 1–6 if the child does not have a full stomach. To anaesthetize the tongue and pharynx in infants, four per cent lidocaine jelly is suckled from a fingertip. In older infants and children, four per cent aqueous lidocaine (maximum dose 3 $mg \cdot kg^{-1}$) is sprayed into the mouth and pharynx. To anaesthetize the nasal and pharyngeal muscosa in infants, five per cent cocaine drops are instilled into the nares (maximum dose 3 $mg \cdot kg^{-1}$). In older children cocaine soaked cotton applicators are inserted into the nose and nasopharynx. Although superior or inferior laryngeal nerve blocks or trans-tracheal injections are not routinely performed in infants and children, the vocal cords and trachea are sprayed with four per cent neubulized aqueous lidocaine prior to bronchoscopy. Aerosolized lidocaine is avoided since laryngospasm can be induced by the cooling effect of the propellant on the vocal cords.

The continuous monitoring of arterial oxygen saturation (SaO_2) by pulse oximetry is recommended with each technique.

Awake orotracheal intubation
Awake orotracheal intubation may be indicated in neonates and in infants and children who are obtunded or in very cooperative children at risk of aspiration (Figures 2, 3 and 5). The awake orotracheal technique includes preoxygenation, continuous insufflation of oxygen through a side port blade, proper positioning and gentle restraint of the child. Intubation attempts should be temporarily discontinued if arterial oxygen saturation (SaO_2) follows below 85 per cent.

Although awake orotracheal intubation is usually a safe choice, attempts at oral intubation in a struggling child may convert partial into complete obstruction either by inducing laryngospasm or by the effects of negative pressure (attempts at crying) on an extrathoracic obstruction. If laryngospasm is suspected, attempt to ventilate with 100 per cent oxygen and positive pressure. If this fails to break the laryngospasm (rarely), one may administer IV succinylcholine, attempt to ventilate with 100 per cent oxygen, and attempt endotracheal intubation. If these manoeuvres fail, rigid bronchoscopy, tracheostomy, or cricothyrotomy is indicated. If the obstruction is secondary to the effects of negative intrathoracic pressure on an extrathoracic obstruction in a crying child, general anaesthesia with spontaneous ventilation and PEEP may be helpful.

Awake, blind or laryngoscopic nasotracheal intubation
Nasotracheal intubation may be indicated when the oral route is unavailable (Figure 3). However, this technique is difficult in the child with large adenoids, and is unsafe in the presence of basilar skull fracture or nasopharyngeal mass. In the awake blind technique, topical anaesthesia is applied and a lubricated endotracheal tube is inserted into the nares. While listening to breath sounds at the proximal end, the tip of the endotracheal tube is passed through the vocal cords during inspiration. If partial laryngoscopy and visualization of the epiglottis or arytenoid cartilages are possible, the endotracheal tube may be guided into the trachea with Magill forceps.

General anaesthesia with spontaneous ventilation
This technique has the advantage of allowing the patient to spontaneously ventilate while the degree of obstruction is assessed, circumvents the effect of negative intrathoracic pressure on a variable extrathoracic obstruction, and helps to define the airway during laryngoscopy and bronchoscopy. It is indicated when visualization of the larynx is likely to be difficult (Figure 3).

Anaesthesia is induced by allowing the spontaneous ventilation of increasing concentrations of halothane in 100 per cent O_2 until the inspired concentration of halothane is four to five per cent. The onset of anaesthesia

which is adequate for manipulation of the airway may be delayed in children with airway obstruction. Adequate anaesthesia is achieved when respiration is diaphragmatic and shallow and when the patient tolerates laryngoscopy with gagging. Children with airway obstruction frequently become more obstructed after they are anaesthetized. If this occurs, perform chin lift, insert an oral or nasal airway, and assist ventilation with PEEP. If complete obstruction occurs, rigid bronchoscopy or tracheostomy is indicated.

Due to its lighter density the administration of helium may be beneficial to the partially obstructed child. To improve ventilation significantly the inspired helium must be at least 60 per cent of the mixture of inspired gases.[22] Since oxygenation may be impaired when helium is used,[23] it is advisable to monitor SaO_2.

Flexible fibreoptic endoscopic intubation

Flexible fibreoptic endoscopic intubation includes four approaches: awake or anaesthetized and oral or nasal. The awake approach is used when airway control is needed before the child loses consciousness. However, endoscopic intubation is usually easier in the anaesthetized child with spontaneous ventilation. Although it may induce epistaxis, the nasal route offers a straight approach from the pharynx to the glottis.

To perform flexible fibreoptic intubation, the child is deeply anaesthetized using general anaesthesia with spontaneous ventilation, first with a face mask, then with a nasopharyngeal tube. Three important factors in successful fibreoptic endotracheal intubation in children are: (1) maintaining the bronchoscope in midline position with a plastic grooved oral airway, (2) retraction of the tongue anteriorly with a heavy silk stitch, and, (3) transillumination of the hypopharynx to indicate that the tip of the bronchoscope is in the proper location.

The smallest available flexible fibreoptic bronchoscope (3.5 mm OD) which has a bending angle and a suction port is the Olympus LF-1. Since this bronchoscope will pass through a 4.0 mm ID endotracheal tube (without the connector), it is useful in large-term and older infants. Of the available Olympus Ultrathin Fiberscopes (1.8–2.7 mm OD) only the 2.7 mm OD model has a bending angle and only the 2.3 mm OD model has a suction port.

The use of adult bronchoscope to intubate small children has been described.[23,25] In one technique, the flexible bronchoscope or laryngoscope is used to visualize the hypopharynx while an endotracheal tube is inserted separately and directed into the illuminated hypopharynx.[24] An alternative technique has been described in which an adult-size fibreoptic bronchoscope is used to visualize the hypopharynx.[25] A cardiac catheter guide wire is threaded through the suction part of the scope and inserted into the trachea. A cardiac catheter is then passed over the guide wire. The endotracheal tube is then slipped over the cardiac catheter and guide wire into the trachea. This technique will aid in the placement of an endotracheal tube as small as 3.0 mm ID.

Rigid bronchoscopic intubation

Rigid bronchoscopic intubation offers several advantages over flexible fibreoptic endoscopic intubation when the oral access is available. The rigid bronchoscope may be passed through an obstruction that would impede a flexible endoscope (foreign body, subglottic stenosis). Other advantages of rigid bronchoscopy include the ability: (1) to manipulate a foreign body, (2) to ventilate the child through the bronchoscope, (3) to diagnose vascular arch anomalies by compression, and (4) to remove thick secretions.

Rapid sequence intravenous induction with cricoid pressure and intubation

In this technique, anaesthesia is induced (after preoxygenation) with intravenous thiopentone ($5\ mg \cdot kg^{-1}$), atropine ($0.020\ mg \cdot kg^{-1}$) and succinylcholine ($1.5\ mg \cdot kg^{-1}$) and cricoid pressure is applied. The limitations of this technique have been discussed.

Cricothyrotomy and tracheostomy

Preparation for cricothyrotomy and tracheostomy should be made before endotracheal intubation is attempted by any technique. When surgical access to the airway is urgently required, tracheostomy[26,27] is preferred over cricothyrotomy. However, cricothyrotomy is an available alternative technique.[28] Although the cricothyroid membrane is poorly defined in children, the cricoid ring is palpable and can be divided to provide access to the trachea. Except for the additional risk of producing cricoid chondritis, the complications associated with cricothyrotomy in children are the same for tracheostomy.

Alternatively, ventilation can be achieved by puncturing the cricothyroid membrane with a #14 plastic intravenous catheter unit, removing the needle and attaching the plastic sleeve to a 3 cc syringe (without plunger) and an adapter from a 7.5 mm OD endotracheal tube and a breathing circuit.

Conclusion

Airway obstruction in infants and children is frequently a life-threatening situation. With proper management of the airway based on a knowledge of the disease process and a knowledge of the various intubating techniques available, morbidity and mortality in these patients can be minimized.

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