The Neonatal Airway

12

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12.1 Introduction

Neonates and their anaesthetic problems are not just equivalent to smaller adults, and definitely not smaller children. This statement is most prominently visible in neonatal airway. The difference in the airway between the neonates and adults/older children encompasses the anatomical, physiological as well as pharmacological aspects of airway management. Effective and safe airway management of neonates requires understanding how these differences can possibly alter and affect the neonatal airway management. A detailed knowledge of the neonatal airway anatomy and a thorough understanding of the respiratory physiology is important to understand their associated clinical implications. The knowledge about the various equipment and procedures used for neonatal airway management related to the anatomy and physiology of the neonate is the key to successful and uneventful airway management in neonates. Prematurity and its potential sequalae come with its own set of problems related to airway management. Wherever needed, the problems of prematurity have been emphasised in the relevant segments. This chapter has following sections under which neonatal airway will be discussed:

1. **Anatomical and physiological aspects**
2. **Airway assessment**
3. **Neonatal airway management: procedures and equipment**
4. **The difficult airway**
5. **Anaesthetic considerations and management in difficult airways**

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12.2 Anatomical and Physiological Considerations

12.2.1 Anatomical Considerations

Anatomically, the neonatal airway will include nose, nasal passages, mouth, oral cavity, pharynx, larynx and finally the glottis, subglottis, and the trachea. Apart from this, the nonairway part of the neonate, i.e., the head, neck, cheeks, and the face may cause problems in airway management.

(a) **The head and neck**: the brain of the foetus grows disproportionately rapidly in-utero and causes a relatively larger head than the body. Proportion of the head compared to the rest of the body is 19% in a neonate compared to 9% in an adult [1]. Also, the neuro-cranium (cranial vault) is larger than the viscero-cranium (face). This makes the skull shape elongated with a prominent occiput. In supine position, the relatively long and prominent occiput causes the head to flex over the neck, an extremely unfavourable position of the airway axis, causing the airway to obstruct easily (Fig. 12.1). Keeping a small roll under the shoulders, with the head in a neutral or minimally extended position, achieves the nearly sniffing position, guaranteeing airway patency. Failure to ensure this leads to a situation of difficult airway, i.e., difficult mask ventilation and poor direct laryngoscopic view. The newborn also has a short neck which makes the head seemingly sitting right over the shoulders. This means there is less length available for flexion of the neck over shoulders, and this makes attaining of the sniffing position more difficult in neonates. Neonates have hypoplastic jaw, small mouth, and small intraoral and pharyngeal spaces. All these peculiarities contribute to the difficult airway in the neonate.

(b) **Small nasal airway**: neonates are preferential or obligate nose breathers. The small intraoral space and large tongue, makes the tongue, in its entire length, nearly in apposition with the hard and soft palates, occluding the passage of air through the mouth. Due to the high position of the larynx (at the level of C3–4 vertebrae compared with C5–6 vertebrae in adults) the resistance to the air flow in the oral airway to reach the glottis is increased. The narrow nasal airways are

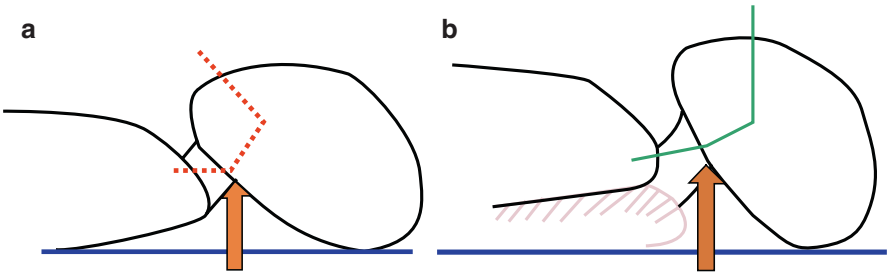

Fig. 12.1 Positioning for airway management in neonates and infants. The orange arrow shows the site of potential obstruction (**a**) relieved by keeping a soft pillow under the shoulders (**b**)

prone to obstruction by secretions or inflammation and can lead to significant respiratory difficulty.

(c) **Tongue and oral cavity**: the large tongue in proportion to the oral cavity can obstruct the airway following loss of muscle tone after induction of anaesthesia, especially with use of muscle relaxants, in the supine position, and difficult mask ventilation and, spontaneous breathing. Recent imaging studies have demonstrated that a major proportion of airway obstruction is also due to the nasopharyngeal and epiglottic collapse [2].

(d) **Larynx**: larynx is more cephalad (C3–4) and descends to adult level with age. This contributes to difficult visualisation of vocal cords during direct laryngoscopy as the angle between the pharyngeal and the laryngeal axis increases (Fig. 12.1). In adults, the angle between the vocal cords and trachea is almost 90° in the antero-posterior direction, while in neonates, it is more oblique and slant, thus hampering glottic view at laryngoscopy [3].

(e) **Epiglottis and laryngeal cartilages**: the epiglottis in neonates is narrow, omega shaped, stiff, proportionally longer and angled away from the axis of the trachea. Other laryngeal cartilages, the arytenoids, corniculate and cuneiform are also proportionally larger compared to the laryngeal inlet. The aryepiglottic folds are closer to midline. All these factors further obscure the glottic view. The large, floppy epiglottis is difficult to be raised on the glosso-epiglottic fold by the curved McIntosh blade. This explains why the glottis is easier visualize by lifting the epiglottis with the straight Miller blade. In a neonate, the hyoid bone is ossified only in the central part, while lateral part is still cartilaginous. Hyoid is the main support for the muscles that hold the cartilages of the larynx in its resting position. During direct laryngoscopy, the traction force applied over the base of the tongue (or vallecula) doesn't lift the unossified hyoid bone effectively and doesn't modify the laryngeal view to aid glottic visualization. To visualise the entire glottic opening the blade of the laryngoscope needs to lift the epiglottis. The unique anatomy of the newborn airway along with the low muscle tone makes it more vulnerable to collapse during inspiration. Use of some continuous positive airway pressure (CPAP) by keeping the pressure-limiting valve or the expiratory port partially closed at induction of anaesthesia and during sedation, helps to keep the airway patent.

(f) **Shape of the neonatal airway**: the paediatric larynx is thought to be funnel shaped as compared to the cylindrical shape in adults. Traditional teaching is that the subglottis is the narrowest part of the neonatal airway. However, some newer MRI studies have demonstrated that narrowest portion of the airway might be glottis and the subglottis may be elliptical rather than cylindrical [4]. This encouraged the use of cuffed tubes in neonates as uncuffed tubes would produce excessive pressure on one side and excessive leak on the other side of a supposedly elliptical sub glottis, leading to suboptimal ventilation and increased chance of aspiration. Recent CT-based studies (CT is considered better than MRI for airway imaging) have shown that cricoid (which is subglottic)

is indeed round shaped in neonates, with a smaller diameter than the anteroposterior diameter of the glottis and is, thus functionally and anatomically the narrowest part of the larynx [1].

12.2.2 Physiological Considerations

(a) **Preferential nasal breathers:** neonates are obligate nasal breathers. Therefore, obstruction to the anterior or posterior nares by congenital (choanal atresia) or acquired (nasal congestion, secretions) condition, could cause obstruction and severe asphyxia.

(b) **Lung volumes and capacities,** especially the functional residual capacity (FRC), are disproportionately low relative to their body size. Their metabolic rate and oxygen requirement is (7–9 mL/kg/min) almost twice that of an adult. This results in a greatly increased ventilatory requirement per unit lung volume for the neonate. During periods of apnea, both these factors, i.e., low FRC and high O_2 requirement, lead to early desaturation, thus complicating the control of an already compromised airway. Use of CPAP and positive end expiratory pressure (PEEP) prevents alveolar collapse and improves FRC during ventilation.

(c) The proportional **airway resistance** is greater in neonates, even at the same airway generations as compared to children and adults due to their small calibre. Application of Poiseuille's law makes this clear. The pressure difference across a lumen change inversely to the power of four with change in radius of the lumen. This means that the relative increase in work of breathing is immensely more when the already small radius of the airways is further decreased by inflammation, edema or secretions.

(d) **Muscles of respiration:** the percentage of **type I muscle fibres** (slow-twitch, high-oxidative fatigue resistant) and the type II (fast-twitch, low-oxidative and fatigue prone) in the diaphragm and intercostal muscles vary with age in infants. The intercostal muscle maturity is achieved by 2 months of age, while diaphragmatic muscles mature by 8 months. The diaphragm, in premature neonates (<37 week gestation) has only 10% type I fibres, compared to 25% in full-term neonates and 55% in older children. The intercostal muscles, in premature neonates have 20% type I fibres versus 45% in full-term neonates and 65% in older children [5]. Increase in work of breathing from any cause is poorly tolerated by neonates as their ventilatory muscles are more prone to fatigue, and this is more pronounced in premature neonates. The need for ventilatory support requirement is earlier in neonates, especially premature, and early ventilatory decompensation should always be anticipated.

(e) The **protective airway reflexes,** coughing and swallowing are not well-developed in neonates. They are extremely sensitive to any stimulation of the airway (secretions and/or mechanical irritants), to which they usually respond with breath holding and laryngospasm and bradycardia. In the premature babies the additional cause of apnea is the nondeveloped or poorly developed brain

centres for regular and cyclic breathing and may occur even without airway irritation.

12.3 Airway Assessment

No clear-cut measurements or predictors of difficult airway exist in neonates. Airway evaluation involves mainly history and physical examination, along with evaluation for comorbid conditions.

12.3.1 History

The medical history should include history of snoring or noisy breathing which may indicate potential obstruction of upper airway, difficulty in breathing while feeding which may indicate a nasal obstruction and any coexisting congenital or acquired medical conditions. Any extra thoracic intraluminal (as in upper trachea or above) will cause inspiratory stridor as the airway lumen will constrict due to the negative intrathoracic pressures generated during inspiration, e.g., in conditions such as extra-thoracic foreign body, laryngomalacia, macroglossia and laryngeal web. Obstruction of the lower trachea or bronchi will lead to exaggerated stridor during expiration as the obstruction increases during forced expiration due to compression of intrathoracic airways.

Relevant medical comorbidities related to prematurity such as bronchopulmonary dysplasia, apnoeic spells, or intraventricular haemorrhage relevant to airway management should also be sought out. History of recent or ongoing upper respiratory tract infection is important to assess the risk of complications, such as laryngospasm, bronchospasm, and desaturation during and post anaesthesia.

12.3.2 Physical Examination

The physical examination should include observation of head contour, shape, facial expression, size of mouth, size and configuration of the palate and mandible as well as features of respiratory obstruction and distress, such as presence of nasal flaring, mouth breathing and presence of retractions (suprasternal, intercostal, and subcostal). A baseline room air SpO_2 should always be a part of neonatal airway examination. Features suggestive of difficult airway include reduced mouth opening during crying, restricted neck mobility, hypoplasia of mandible or maxilla or both, dysmorphic features of the face, abnormalities of ear, facial cleft, cleft lip and palate, and abnormalities or mass of the neck. These are usually quite evident on the examination and should not be missed. Intraoral, pharyngeal, and laryngeal masses may, however, be missed if not given enough thought during airway examination. Some obvious signs of congenital disease with airway implications should be looked for. Bilateral microtia has been shown to be associated with difficulty in visualising the

Table 12.1 Syndromes associated with airway problems

Syndrome	Associated airway abnormalities
Achondroplasia	Midfacial hypoplasia, small nasal passage, and mouth
Congenital hypothyroidism	Large tongue
Crouzon syndrome	Maxillary hypoplasia with V shaped palate, large tongue, OSA
Goldenhar syndrome	Hypoplastic zygomatic arch, mandibular hypoplasia, macrostomia, cleft palate, tracheoesophageal fistula
Hurler syndrome	Coarse facial features, short neck, tonsillar hypertrophy, narrowing of laryngeal inlet and tracheobronchial tree
Hunter syndrome	Coarse facial features, tracheomalacia, macrocephaly, macroglossia
Pierre Robin sequence	Hypoplastic mandible, high arched cleft palate
Treacher Colins syndrome	Malar and mandibular hypoplasia, cleft lip, choanal atresia, macrostomia or microstomia
Down syndrome	Small mouth, hypoplastic mandible, protruding tongue
Charge Syndrome	Coloboma of the eye, Heart disease (TOF), Atresia of choanae. Retarded growth or development, Genital and Ear abnormalities

laryngeal inlet and may be associated with mandibular hypoplasia [6]. Facial haemangioma is associated with Sturge–Weber syndrome and may be indicative of an airway haemangioma as well. A list of syndromes with associated airway problems is provided in Table 12.1.

Presence of encephalocele, hydrocephalus and meningomyelocele can interfere with optimal positioning for airway management. Presence of a coexisting medical disease can affect drug choice during airway management. Hemodynamic instability and/or congenital heart disease may preclude use of certain premedicants and other anaesthetic agents that may need to be provided for hemodynamic management during airway control. Neonates with necrotizing enterocolitis, omphalocele, and gastroschisis have a high risk of aspiration and have significantly diminished FRC, making them more susceptible to hypoxemia and desaturation [7].

12.3.3 Diagnostic imaging

Diagnostic imaging is usually not possible as the procedure itself may need sedation and anaesthesia, thus mandating airway management. Imaging studies are undertaken only if the need for airway management is not imminent and appropriate personnel and equipment needed to manage airway are available. ***Radiographs*** of the soft tissue of head and neck may provide insight about the aetiology and site of airway obstruction if present/suspected. ***Endoscopic evaluation*** of the airway with mucosal local anaesthetic application can be useful in neonates if a glottic pathology is being investigated. The spatial resolution of airway structures is best with ***computed tomography*** due to its superior discrimination of the air/tissue interface.

12.4 Neonatal Airway Management: Procedures and Equipment

12.4.1 MASK Ventilation (MV)

The practice and technique of mask ventilation in neonates differs slightly from that in adults because of the anatomical and physiological challenges as described previously. While choosing a mask for a neonate it is important to choose one with minimal external dead space, ease of application on slightly flat facial contours and ability to see the underlying face of the baby.

Face masks of various sizes and shapes for neonatal airway management are available (Fig. 12.2) (Table 12.2). Commonly used face masks are the anatomical face mask, plastic transparent anaesthesia face mask with syringe adjustable air-cushioned rim, which on inflation/deflation can be altered to match the contour of the patient's face, and the Rendell–Baker–Soucek (RBS) mask. The use of clear plastic mask allows visualisation of the mouth, vapours of the expired air, secretions, vomitus, and lip colour. The RBS mask was specifically designed for children under 10 years of age and is especially suited for neonates. It is made of malleable rubber or silicone and allows a proper face seal and can fit a variety of facial configurations. Its triangular shaped body minimises the dead space (3 mL in size 0 and 4 mL in size 1).

12.4.1.1 Technique of Mask Ventilation:

The objective of a good mask ventilation is to ventilate the patient effectively, with minimal inflation pressure, reflected by adequate chest expansion and absence of gastric insufflation The commonly used techniques for mask ventilation include (Fig. 12.3):

i. ***One hand technique (E–C clamp technique)*:** the thumb and the index finger are placed on the body of the mask to form a C, while the remaining three fingers are placed on the inferior surface of the mandible to form an E.

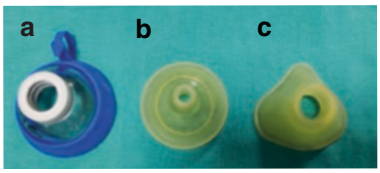

Fig. 12.2 Face masks for neonates. (**a**) Plastic transparent mask with syringe adjustable air-cushioned rim. (**b**) Anatomical face mask. (**c**) RBS mask

Table 12.2 Types and sizes of face masks in neonates and infants

	Anatomical mask	Transparent plastic mask	Rendell-Baker-Soucek mask
Preterm	–	00	0
Infant	0	0	1
Small child	1	1	2

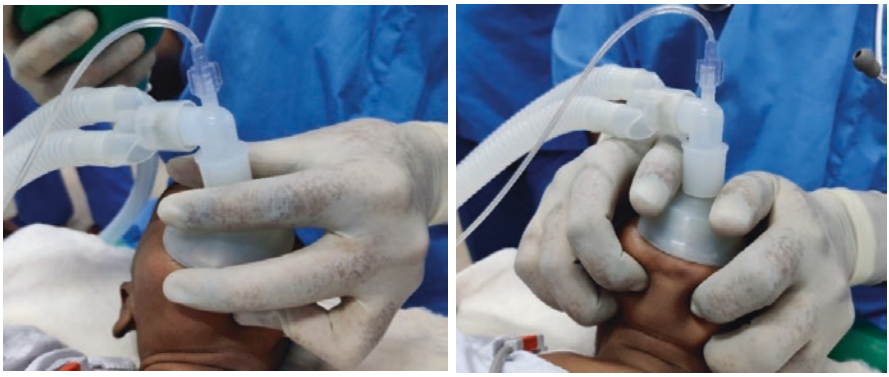

Fig. 12.3 Mask ventilation techniques—one hand and two hand holding mask holding

ii. ***Two handed jaw thrust technique:*** this technique is employed if ventilation is not possible by single hand. In this, both the thumbs are placed over the mask, while index and middle fingers are used to lift the mandible.
iii. ***Claw hand technique:*** the anaesthesiologist stands by the side of the patient, instead of the head end. The facemask is applied with right hand with the palmar surface facing slightly upwards and to the left side of the anaesthesiologist. The ring finger and the middle finger are placed under the right and left side of the angle of the mandible, respectively. The index finger and thumb encircle the body of the mask on the face with a tight grip. This technique has been suggested for babies undergoing short ophthalmological procedures as the head-end of the table is occupied by the ophthalmologist [8].

The commonest error during mask ventilation is compression of soft tissue in the submental triangle with the fingers of proceduralist, partially occluding the airway. Care should be taken that the fingers rest on the bony ridge of the mandible and not on the soft tissue. During mask ventilation, the mouth of the neonate should always be kept open, and mandible translocated anteriorly to lift the tongue away from the posterior pharyngeal wall and palate.

12.4.2 Oropharyngeal Airways (OPA)

The large tongue and the collapsible oropharynx predispose the obstruction of oropharynx during induction of anaesthesia. If optimal ventilation is not possible despite a good technique, an OPA of appropriate size can be used to relieve the obstruction. The size needed corresponds to the distance between the angle of the mouth and the angle of the mandible. Usually, size 00 for pre-term and 0 for term babies is appropriate. The tip of an inappropriately small OPA will push against the base of the tongue further aggravating the obstruction, while a longer OPA may push the epiglottis onto the glottis, worsening the obstruction. Care should always be taken to avoid trauma to the lips, tongue, and palate during insertion of the OPA.

12.4.3 Supraglottic Airway (SGA) Devices

With advancements in the design, multiple SGA devices are now available for use in neonates and infants. The functional elegance of the SGA is its ease of insertion while providing adequate airway patency. SGAs have found a unique place in the management of already difficult neonatal airway. However, the success rate of placement of SGAs in neonates is less than that in adults, and skills and equipment for alternative methods to secure the airway should always be available.

Indications for SGA: indications include elective airway management in diagnostic procedures, short surgical procedures, as a rescue device for managing difficult mask ventilation and intubation, and for preoxygenation in neonates, where low lung compliance and poor cardiopulmonary reserves prevent effective preoxygenation with face mask. SGAs are now increasingly being used for neonatal resuscitation in delivery rooms and for surfactant administration. An advantage is that it can be inserted in an awake neonate after intraoral local anaesthetic application.

Currently, the following SGAs are available for use in neonates: (Fig. 12.4)

i. LMA Classic™, LMA Proseal™: Size 1(<5 kg)
ii. i-gel™: Size 1 (2–5 kg)
iii. Ambu AuraOnce™: Size 1 (<5 kg)
iv. Air-Q™ LMA (laryngeal mask airway): Size 0.5 (<4 kg)

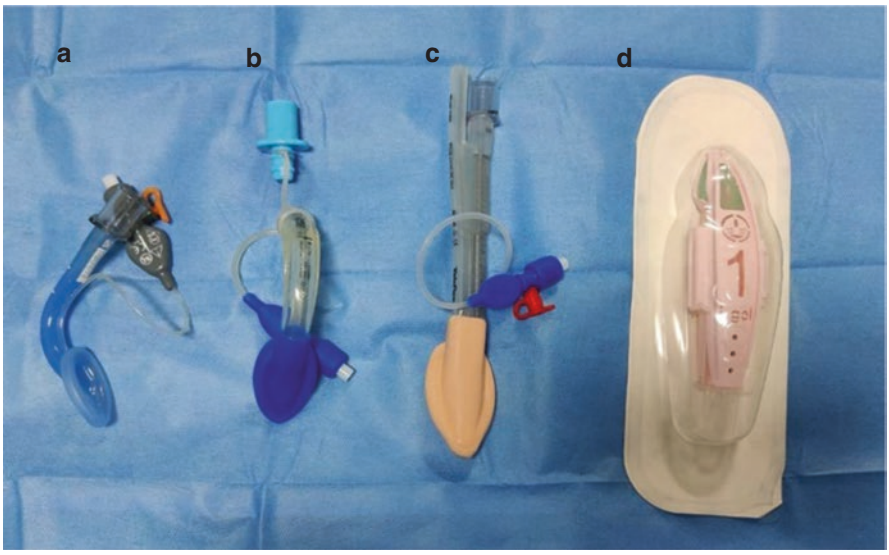

Fig. 12.4 Supraglottic airway devices. (**a**) Ambu AuroOnce™. (**b**) Air-Q™ LMA. (**c**) LMA Proseal™. (**d**) i-gel™ LMA

Use of SGAs in Neonates: troubleshooting

- If the SGA is inserted too far (which can be easily done by novices) it can easily enter the oesophagus. The oesophagus can get intubated and distended by the SGA tip. This can be diagnosed immediately due to lack of signs of lung ventilation despite easy and smooth placement. This happens if the size of SGA is too small and can be resolved by slight withdrawal of the device or choosing one size larger.
- The SGA may bend the epiglottis over the laryngeal inlet causing airway obstruction. The large and floppy neonatal epiglottis is more prone to cause glottic obstruction Repositioning of the SGA may help, but if ventilation is unsatisfactory, endotracheal intubation may be required [9].
- The tip of the SGA can fold on itself during insertion and can be resolved by withdrawing and repositioning or by gently sweeping on the dorsal surface of SGA with the finger.
- The SGAs can get displaced while in use, in a neonate, and cause stomach distension and impedance to lung expansion. This is common with 1st generation SGAs (without gastric drainage tube). A correctly sized 2nd generation SGA, e.g., LMA Proseal and i-Gel, form a better seal with the peri glottic tissues and may be safer in neonates. In addition, the in-built drainage tube aids in venting of gastric air thus preventing gastric distension. They can be used as a conduit for endotracheal tube (**ETT**). A 3 mm ETT can usually be passed through the i-Gel, LMA classic and Air-Q SGAs.

12.4.4 Endotracheal Intubation

a. Technique of Endotracheal Intubation

Optimal Positioning and Selection of Laryngoscope Blade

Unlike adults, oral, pharyngeal, and laryngeal axes in infants are better aligned by simple extension of the head rather than sniffing position. Neonates due to their larger occiput obstruct the airway when placed on a pillow, due to flexion of head. Hence, optimal position for laryngoscopy will be a slight head extension (without using pillow) and placing a small roll beneath the shoulders (please see the section on Anatomy).

The laryngoscope blades commonly used in neonates are straight Miller, Oxford or curved Mcintosh blades (Fig. 12.5). A straight blade is more suitable in neonates because of its more efficient elevation of the epiglottis, giving a clearer view of the glottis. Miller's straight blade sizes 0 and 1 are used in term babies, while size 00 is reserved for extreme premature (<27 weeks of gestation) or low weight <750 g. Based on their experience, some anaesthesiologists prefer the curved MacIntosh type blades 00, 0 and 1 (Table 12.3).

b. Size of Endotracheal Tube (ETT)

ETT sizing in the neonatal population is largely predetermined. Ideally, for any age group, the largest sized ETT should be chosen to minimise airway resistance while limiting undue pressure on the subglottis and trachea. The general

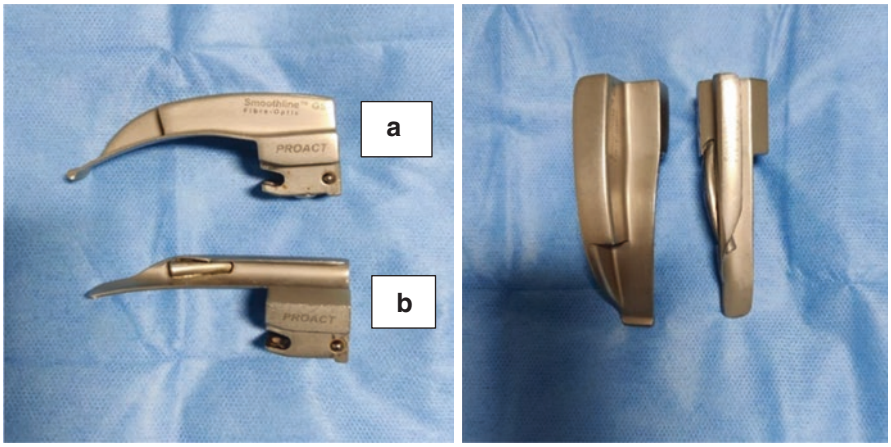

Fig. 12.5 Laryngoscope blades size 0. (**a**) McIntosh. (**b**) Miller

Table 12.3 Sizes and length of miller and mcintosh blade for use in neonates

	Miller blade		McIntosh blade	
	Size	Length(mm)	Size	Length(mm)
Premature neonate	00	62	–	–
Term neonate	0	77	0	83
Infant	1	102	1	92

Table 12.4 Endotracheal tube size (ID mm) and distance for insertion in neonate by age

Age	ET Uncuffed	ET Cuffed	Distance of insertion (cm)
Preterm			
1000 g	2.5	–	6–7
1000–200 g	3.0	–	7–9
Term	3.0–3.5	3.0–3.5	9–10

recommendation is to use an uncuffed 2.5 mm ID ETT for preterm weighing up to 1000 g, 3 mm ID for preterm ranging in weight from 1000 to 2500 g and 3.0 to 3.5 mm ID cuffed or uncuffed ETT for term neonates (Table 12.4).

During intubation, ETT size of 0.5 mm ID smaller or greater than the anticipated size should always be available. Neonates with Down syndrome may require a smaller ETT than predicted. The length of the trachea (vocal cords to carina) in neonates and infants up to 1 year of age varies between 5 and 9 cm [10]. In preterm neonates, trachea is shorter. Therefore, it is important to observe for symmetry of the chest expansion and equality of breath sounds on auscultation in the axillae and apices as well. Auscultation on the anterior chest wall may not be reliable as the breath sounds may reverberate across the precordium in small children. The popular rule of 7–8–9 gives a guide on the depth of insertion of the **ETT** (Table 12.4). Babies weighing 1 kg are intubated to a depth of 7 cm, 2 kg at 8 cm and 3 kg at 9 cm

Table 12.5 Implications of uncuffed and cuffed tubes

Uncuffed tubes	Cuffed tubes
Greater internal diameter (id), Lower resistance	Lower exchange rate
In elliptical epiglottis can produce pressure on one side and excessive leak on the other	Less laryngeal oedema and post extubation stridor
Leakage, suboptimal ventilation	Leaks can be adjusted ensuring adequate ventilation
Increased OT pollution	Allow less fresh gas flow (FGF)
Inaccurate control of $EtCO_2$	Accurate control of $PaCO_2$
Increased chance of aspiration	Less OT pollution
Increased tube exchange rate	Needs cuff pressure monitoring (<20–25 cm H_2O)

c. Choice of ETT: Cuffed vs Uncuffed

The essential differences between uncuffed and cuffed tubes are highlighted in Table 12.5.

12.4.4.1 Microcuff ETT

These are high-volume low-pressure cuffed ETTs made of ultrathin polyurethane of 10 μm thickness (compared to 50–70 μm in PVC tubes). The cuff is short and more distally placed along the shaft as the Murphy's eye has been removed. On inflation, the cuff expands below the subglottis in the upper trachea, providing a seal with low cuff pressure, usually less than 20 cm H_2O. The trachea is sealed at upper trachea (rather than at sub glottis), where the posterior membranous wall can stretch and produce a complete seal. The pressure over the cricoid ring and the risk of subsequent subglottic stenosis is also reduced. The thin cuff allows complete and uniform surface contact with minimal folds. The risk of endobronchial intubation is reduced with these tubes. The cuff should be inflated to minimal pressure that seals the air leak. Microcuff ETT are available from size 3 onwards and can be used in term neonates >3.0 kg (Figs. 12.6).

12.4.5 Video Laryngoscopy (VL)

VL has revolutionised airway management. Surprisingly very little high-quality evidence is available regarding its superiority to traditional laryngoscopy when used for endotracheal intubation in neonates. One reason for this is the lack of well-controlled studies in this population due to multiple ethical reasons, and the few available studies do describe its superior image quality compared to traditional laryngoscopic view. However, this has not been correlated with the success rate of intubation or to time to intubate.

VL can be used as the primary device or as a rescue/back up device for direct laryngoscope. They are of two types, channeled and nonchanneled. The nonchanneled VL are equipped with an optical system in the blade with either an inbuilt or a stand-alone viewing window, and include C-MAC® VLS, GlideScope®, Multiview Scope®, and Truview PCD™ Pediatric. The channeled VL has an optical system with

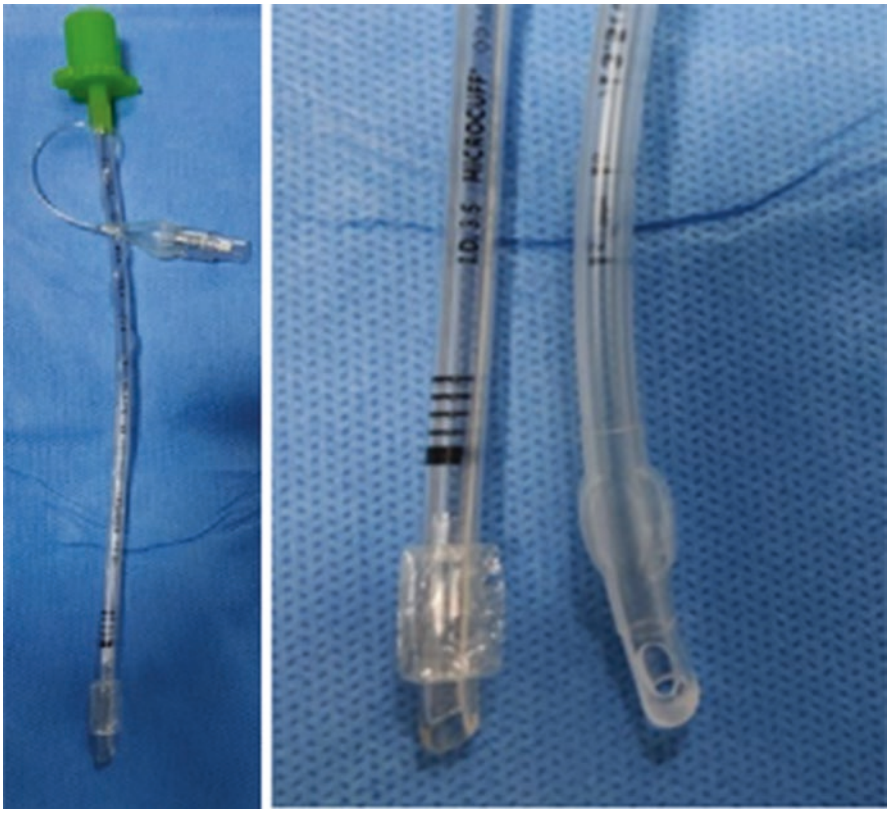

Fig. 12.6 Microcuff endotracheal tube - absence of Murphy eye and distally placed cuff

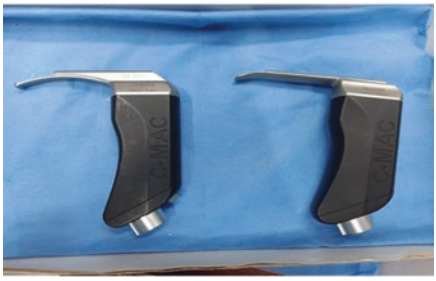

Fig. 12.7 Video laryngoscope (C-MAC) blades size 0: Macintosh and Miller

a viewing window as well as an inbuilt channel in the blade for preloading an ETT. These include the King Vision®, AirTraq™, and AirWay Scope® [11]. The blade designs include Miller, McIntosh, hyper angulated D-blades or customised blades which are used when optimal neck extension is not achievable. In neonates, Miller 0,1 or McIntosh 0 size may be used (Fig. 12.7). The method of laryngoscopy

Table 12.6 Various sized fibre optic bronchoscope available in neonate

Outer diameter (mm)	Working channel (mm)	Suction Channel mm)	ET size (minimum)	
2.2	Yes	No	3.0	<6 months age
2.8	1.2	1.2	4.0	Any Pediatric age

is similar as in direct laryngoscopy. In some, the manufacturer recommendations describe midline insertion of the blade without sweeping the tongue and is useful for those not proficient with neonatal intubations.

The greatest advantage of VL is as a good teaching and training tool, since the laryngoscopic view is visible to all, and can even be projected to a larger screen for greater viewability, while at the same time, the teacher can help the performer with the intubation as well [12].

12.4.6 Fibreoptic bronchoscope (FOB)

FOB may be required for airway management in babies with diagnosed cervical inflexibility (Klippel–Feil syndrome) or cervical instability (Achondroplasia, Down Syndrome, and rarely trauma). Many reports of use of FOB for oral and nasal intubation in neonates are available for various congenital conditions, such as syngnathia, Pierre Robin Syndrome, oral and pharyngeal tumours. Any condition where neck movements or intraoral/pharyngeal space is restricted, the flexibility of the FOB is advantageous. Various sized FOBs are available for intubation in neonates (Table 12.6).

The oral approach may be less stimulating than the nasal and better tolerated in neonates but is more difficult to negotiate. On the other hand, the nasal route may be technically easier but can cause nasal trauma and bleeding. A gentle jaw thrust is helpful in opening the posterior pharyngeal and supraglottic spaces and in the negotiation of the FOB. The size for neonates lacks a working channel and suction port, and so neither secretions can be cleared nor O_2 can be administered. This necessitates administration of O_2 using alternative device during the procedure. Another problem encountered is the resistance to the passage of ETT. This can be overcome by withdrawing the ETT a few millimetres, changing the direction of the bevel and reinserting. Usually, a bevel facing up for nasal intubation and the bevel facing down for oral intubation is helpful. FOB guided intubations can be difficult in neonates not just due to an anatomically difficult airway but also due to the minimal O_2 reserve. Methods of continuous O_2 insufflation as well as maintenance of spontaneous respiration should be actively followed during FOB guided oral and nasal intubations both in awake as well as sedated neonates. In difficult cases, LMA guided FOB aided endotracheal intubation can be done.

12.4.7 Rapid Sequence Induction (RSI) and Intubation (RSII) in Neonate

Rapid Sequence Induction and Intubation (RSII) describes a coordinated, sequential process of preparation, anaesthesia, and paralysis to facilitate emergency tracheal intubation in patients who are at high risk for regurgitation and aspiration. Classic RSII puts paediatric patients at risk of complications, such as desaturation, traumatic intubation, and hemodynamic morbidity. Neonates, especially, may not allow complete preoxygenation, may be difficult to intubate and with decreased apnoea time available, may quickly decompensate to hypoxia and bradycardia. A 'controlled' RSII (cRSII) technique has been described for paediatric patients and may be suitable for neonates rather than the classic RSII used in adults [13]. The changes in RSII protocol for neonates may include all or some of the following modifications:

- Use of opioids and/or benzodiazepines to decrease induction drug dosages and decrease stress response to intubation
- Avoiding cricoid pressure altogether or releasing just before intubation
- Gentle face mask ventilation during the time waiting for peak effect of muscle relaxants to occur

The equipment and methods for intubation essentially remain the same with use of cuffed ETT.

12.5 The Difficult Neonatal Airway

Airway management in neonates is categorized as being difficult even without any anticipated or unanticipated added medical, anatomical, or physiological challenges.

12.5.1 Definition

Difficult intubation (DI) is defined as endotracheal intubation requiring three or more laryngoscopy attempts by an experienced performer. A multicentric retrospective review reported DI in 14% of the neonates with a fourfold increased odds for severe desaturation [14]. DI was more common in premature neonates (<32 week gestational age) and weighing <1500 g.

12.5.2 Identifying of Difficult Airway

Incidence of tracheal intubation associated adverse events is approximately 20–40% of all neonatal intubations. It is important to recognize circumstances that can cause airway obstruction or difficulty. Upper airway obstruction, a known history of

Table 12.7 Causes of difficult airway encountered in neonate and infants

Craniofacial abnormalities	Compromised airway	Cervical spine anomalies
Pierre Robin sequence	Bilateral choanal atresia	Down syndrome
Treacher Collin syndrome	Subglottic stenosis	Klippel Feil malformation
Goldenhar syndrome	Tracheomalacia	Goldenhar syndrome
Mucopolysaccharidosis	Ludwig s angina	Mucopolysaccharidosis
Achondroplasia	Acute epiglottitis	–
Crouzon syndrome	Foreign body	–
–	Trauma	–

difficult airway, micrognathia, limited mouth opening, limited neck extension, cleft palate and short thyromental distance are generally indicative of a difficult airway. Neonates belonging to a syndrome/sequence which involves airway anomalies along with other systemic involvement need to be identified. A list of syndromes and conditions associated with features leading to difficulty in airway management is provided in Table 12.7. Careful preanesthetic evaluation and clinical assessment and recognition of possible signs and symptoms of these conditions will reduce airway management-related complications.

12.5.3 Approach to Difficult Airway

The safest approach to manage a difficult airway is to formulate a plan that includes several contingencies for failure or loss of airway, a clear communication between the members of the team and specific details to facilitate the process. All equipment should be checked to ensure good working condition and all the resuscitation drugs should be prepared in appropriate dilutions and dosages. Equipment in appropriate sizes should include, but may not be restricted to, tracheal tubes and SGA devices, laryngoscope blades, stylets, facemasks, OPA, suction devices, reliable O_2 source, and vascular access equipment.

12.5.4 Management Nonsurgical

Nonsurgical: A reasonable principle in the management of difficult airway is to maintain spontaneous ventilation. Topical anaesthesia can be used in conjunction with sedation or general anaesthesia to blunt airway reactivity in whom spontaneous ventilation is to be preserved. Decision-making must start with the choice of sedation management. A predetermined place in the continuum of anaesthesia ranging from awake, semiawake, sedative/local anaesthesia, or general anaesthesia has been described in literature for the management of a neonate with difficult airway. Adequate visualisation of the vocal cords is a mandatory step for successful intubation. A recently conducted trial demonstrated that the early use of VL with standard blade improved the first-attempt success rate with reduced complications in anaesthetised neonates [15]. The advantages of VL are obvious and useful in difficult neonatal airway. It can facilitate intubation in most cases, while SGA and FOB may be useful for cases with

Table 12.8 Various tracheostomy tubes (TT) and sizes (mm) available for neonates

TT	ID	OD	Distal length	Cuff	Material
Bivona (NEO)	2.5	4	30	Y	Silicone
	3	4.7	32	Y	
	3.5	5.3	34	Y	
	4	6	36	Y	
Shiley (NEO)	2.5	4.2	30	Y	PVC
	3.0	4.8	30	Y	
	3.5	5.4	32	Y	
	4.0	6.0	34	Y	

anticipated difficult mask ventilation. Patients with anatomical anomalies above the larynx can be managed with SGA, FOB, or combination of the two.

In case of unanticipated difficult airway, call for help immediately. The goal will be to maintain oxygenation and ventilation. Consider an early use of VL. In case of failed intubation, ventilation should be attempted by facemask or SGA, and if possible, then intubation may be attempted via SGA and FOB. In case of failed intubation and inadequate ventilation, proceed to rescue techniques, such as surgical tracheostomy.

Surgical airway–tracheostomy: invasive airway access is particularly challenging in neonates. The diameter and length of the subglottic airway varies with gestational age. The internal diameter of subglottis in a newborn is 3.5–4 mm, 3 mm or less in premature newborn [16], and tracheal length (glottis to carina) is about 40 mm (4 cm). It is thus important to use an appropriate size of tracheostomy tube (TT) in neonates. Needle cricothyroidotomy may not be a practical approach as the cricothyroid membrane is difficult to locate and too small to accommodate even an appropriate tube.

Paediatric TTs are usually single lumen without inner canula. Currently, fenestrated TTs for neonates are not available. Paediatric tubes are manufactured in standard neonatal and paediatric sizes (Table 12.8). For children up to 5 kg neonatal sizes are used. It is important to be ensure that the tip of TT is not endobronchial. A common way to determine the correct placement of the tube is by performing a flexible tracheoscopy through the tube, after the procedure itself.

The common indications for tracheostomy in neonates include the need for prolonged ventilation, facilitation of ventilator weaning and upper airway obstruction (Table 12.9). In preterm neonates, BPD requiring ventilatory support is a common indication for tracheostomy [17]. The procedure and care during and after neonatal tracheostomy are same as standard paediatric tracheostomy. The neonatal physiology and anatomy should always be under consideration while performing them. The tracheal incision for the tracheostomy is vertical. Stay sutures are used which are useful for rapid identification of the newly created stoma in case of accidental decannulation.

Complications: neonatal tracheostomies have high morbidity and mortality (1.5–8.9%) especially in the presence of cardiac risk factors [18].

a. Short-term complications
b. Long-term complications

Table 12.9 Indications for tracheostomy in a neonate

i.	Craniofacial disorders with upper airway obstruction
ii.	Cardiopulmonary disease requiring long term positive pressure ventilation
iii.	Neurological disorders, congenital and acquired
iv.	Acquired or congenital glottic, subglottic or tracheal stenosis
v.	Acute airway infections (epiglottitis, tracheitis, croup)
vi.	Congenital high airway obstruction syndrome (CHAOS)

Short-Term Complications
- Bleeding
- Thyroid gland injury
- Skin pressure necrosis
- Accidental decannulation
- Creation of a false track
- Blockage by mucous plug or clot
- Tracheal ulceration

Long-term complications
- Granulation tissue formation
- Ulceration/erosion: anteriorly leading to trachea-innominate fistula and posteriorly leading to tracheoesophageal fistula
- Tracheal stenosis

The management of these complications, as with the management of tracheostomy is complicated in neonates and expert help should be called for as soon as feasible. All care should be taken to prevent the occurrence of these complications.

12.6 Anesthetic Considerations of Difficult Airway

Two conditions deserve special mention which may prove fatal if not identified and managed early.

12.6.1 Choanal Atresia (CA)

Congenital CA is the complete blockage of the posterior nasal opening. This anatomical deformity occurs due to enlargement of the vomer bone and medialization of the pterygoid plate during the intrapartum growth. The atresia can be categorised as membranous or bony, and unilateral or bilateral, with majority being unilateral. Bilateral posterior CA is associated with high mortality, especially in neonates with congenital heart disease and tracheoesophageal fistulas.

Preoperative considerations: bilateral CA is detected soon after birth due to early symptoms associated with severe respiratory distress. Unilateral CA is often

Table 12.10 Anatomical mechanism of upper airway obstruction in laryngomalacia

Type 1	Cuneiform cartilages are drawn inwards during inspiration
Type 2	Long tubular epiglottis curls on itself
Type 3	The arytenoids collapse inwards
Type 4	The epiglottis is displaced against the posterior pharyngeal wall or vocal folds
Type 5	Short aryepiglottic folds
Type 6	Overly acute angle of the epiglottis at the laryngeal inlet

not detected until adolescence when patients present with nasal congestion. Association with CHARGE syndrome is observed in 75% of the patients with bilateral CA. Other congenital anomalies associated with CA include humeroradial synostosis, mandibulofacial synostosis, microcephaly, micrognathia, palatal defects, Treacher–Colin syndrome and other craniofacial dysmorphisms [19]. They are also at increased risk of laryngomalacia. Bilateral CA is an emergency and need immediate airway management, often tracheostomy. Preparation for the difficult airway and considerations for the associated anomalies remain the chief concerns.

Intraoperative considerations: mask ventilation may be difficult. The protocols and practices for difficult airway should be followed. The presence of surgical team is desirable in the event of emergency tracheostomy. Muscle relaxants may be used to facilitate surgery after securing airway.

Postoperative considerations: patients with CHARGE syndrome are at increased risk for airway events and should be watched closely. Neonates should be extubated in controlled setting, either in the theatre with all preparations for reintubation or in NICU.

12.6.2 Laryngomalacia

Congenital laryngomalacia is the most common cause of stridor in neonates, usually presenting within 2 weeks of birth. The neonates present with inspiratory stridor that worsens with feeding and in supine position. The anatomical mechanisms for the upper airway obstruction in laryngomalacia are enumerated in Table 12.10 [20]. Only 5–10% require surgical treatment involving division of the aryepiglottic folds, resection of excess arytenoid tissue, and suspension of the prolapsing epiglottis. Supra glottoplasty is the most common procedure performed in neonates with severe laryngomalacia in stridor.

Preoperative considerations: severe laryngomalacia can cause upper airway obstruction, cyanotic spells, feeding difficulties, failure to thrive, corpulmonale, and developmental delay. Neonates may present with cardiorespiratory failure. The spectrum of signs suggestive of cardiorespiratory failure ranges from nasal flaring to chest retraction, tachypnoea, tachycardia, and cyanosis. Feeding difficulties occur because of gastro-oesophageal reflux secondary to upper airway obstruction. The diagnosis of laryngomalacia is usually made by flexible nasal endoscopy. The use of

antisialogogue, such as atropine (20 mcg/kg), prior to induction of anaesthesia can be considered.

Intraoperative considerations: babies with laryngomalacia frequently have easily recognizable difficult airway features, making the conventional methods of securing the airway difficult. The altered anatomy may sometimes require urgent tracheostomy. Intubation is usually difficult due to the associated large overhanging epiglottis, redundant arytenoid tissue, and the inspiratory positional stridor. Inhalational induction in the lateral position while maintaining spontaneous respiration is a safer option. Intubation with VL or FOB is the gold standard. Supra glottoplasty necessitates an obstructed airway, clear view of the structures and use of laser for excision. Considering a shared airway by the surgeon and anaesthesiologist and risk of airway fire and trauma, a well-charted airway plan is required. The options for ventilation include spontaneous ventilation, intermittent positive pressure ventilation, apnoeic ventilation, and jet ventilation depending on the experience of the anaesthesiologist and availability of the equipment.

Postoperative considerations: tracheal extubation should also incorporate an effective comprehensive plan to prevent cannot intubate and cannot ventilate situation. The neonate should be monitored and closely watched for signs of airway obstruction preferably in NICU. Humidified O_2, racemic epinephrine and dexamethasone may be required in the event of airway obstruction.

12.7 Summary

Neonates form a unique subset of paediatric patients with significant differences in their anatomy and physiology and these differences have a huge impact on the airway management and its outcome. Neonatal anatomy predisposes to airway obstruction. The "anterior airway" mandates modification of intubation technique. Failure to modify medical management appropriate to the neonate can lead to complications, such as loss of airway with failed ventilation. There are guidelines for difficult airway management in paediatric patients, while none specifically exists for neonates. Therefore, it is of utmost importance to formulate a plan that includes several contingencies for failure or loss of the airway including a clear communication between the members of the team. Early usage of SGA and VL should be considered in the airway management plan. Neonatal airway management is required at birth for resuscitation or subsequently for elective or emergency surgical procedures. It is a core skill in neonatology and proficiency in managing the difficult airway may be lifesaving in an acute emergency.

12.8 Conclusion

Airway management in neonates requires a thorough knowledge of airway anatomy, respiratory physiology as well as familiarity with the equipment available for the procedure. Knowledge and competence in basic airway management skills such

as mask ventilation, laryngoscopy, SGA placement, and endotracheal intubation is acquired with experience. Successful management of difficult airway in a neonate is a multidimensional challenge to the anaesthetist and is to be approached with caution, and requisite preparation to face unanticipated problems.

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