Chapter

21

Anaesthesia for ENT Surgery in Children

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Introduction

Ear, nose and throat (ENT) procedures are amongst the most common operations in children. They present numerous challenges to the anaesthetist, including the shared airway, increased incidence of perioperative respiratory adverse events (PRAE), high incidence of postoperative nausea and vomiting, emergence delirium, numerous day-case procedures, high turnover lists and comorbidities with anaesthetic implications. Airway surgery can be particularly challenging for the anaesthetist and surgeon alike and requires careful preparation, excellent communication and close teamwork as well as a high-level of expertise and flexibility.

Preoperative Assessment

Preoperative assessment of children undergoing ENT procedures should include information about sleep disordered breathing (SDB), recent upper respiratory tract infections (URTIs) and congenital syndromes, in addition to the usual assessment.

Obstructive Sleep Disordered Breathing

Obstructive SDB has become the most common indication for adenotonsillectomy. It is a syndrome of upper airway dysfunction during sleep, characterised by snoring and/or increased respiratory effort secondary to upper airway resistance and pharyngeal collapsibility. It is of significance because it is associated with an increased risk of laryngospasm, airway obstruction and oxygen desaturation perioperatively. Children who will benefit from adenotonsillectomy are those with upper airway obstruction whilst awake; abnormal sleep study in combination with SDB symptoms, such as snoring; conditions predisposing to SDB, such as mandibular hypoplasia; SDB and complex conditions, such as Down syndrome, Prader–Willi syndrome; or sickle cell disease associated with obstructive SDB. Notably, obstructive sleep apnoea (OSA) is also associated with an increased sensitivity to the respiratory depressant effect of opioids, which should be used with caution in severe OSA, and their effects monitored postoperatively. Rarely, severe OSA can result in hypoxia, which may lead to pulmonary vasoconstriction, right ventricular hypertrophy and right heart failure requiring high-dependency unit (HDU) management pre- and/or postoperatively.

SDB is measured objectively using polysomnography (PSG) and its severity is determined by the apnoea-hypopnoea index (AHI). The AHI is the number of mixed, obstructive and central apnoeas and hypopnoeas per hour of total sleep and can be predictive of the need for admission and level of postoperative monitoring required. Mild obstructive sleep apnoea syndrome (OSAS) is frequently diagnosed with obstructive AHI one to five episodes per hour, moderate OSAS with obstructive AHI >5–10 episodes per hour and severe OSAS with obstructive AHI >10 episodes per hour. There is little consensus about the admission criteria for children with SDB and OSA, especially in those requiring adenotonsillectomy, and different centres will have their own guidelines for suitability of procedure in their institution and monitoring and admission. A significant practical consideration with the PSG is that it requires an overnight stay in hospital and has limited availability as a result. It is important to remember that severe OSA in small children can limit growth and development, and undue delay of surgery because of poor availability of 'objective' quantification of OSA can be very detrimental. A pragmatic approach is therefore advocated, including history from parents, evidence of failure to thrive and poor growth and general development. Surgery should not be delayed unduly because of the lack of preoperative OSA assessment with PSG. Home-based sleep

apnoea testing devices are being investigated as alternatives for the assessment of OSA in children and may assist in risk stratification and better use of resources. This includes the McGill score, which can also be used to stratify the severity of OSA. It ranges from 1 (normal or inconclusive) to 4 (severely abnormal) according to the number of clusters and the depth of desaturation events seen in overnight oximetry. Compared to full polysomnography, the McGill score has a high positive predictive value and a low negative predictive value. The current European Respiratory Society and American Academy of Pediatrics guidelines suggest that an abnormal overnight oximetry based on McGill criteria can accurately detect OSA of at least moderate severity, but a negative result does not exclude OSA with certainty. Children with severe OSA may still develop airway obstruction after surgery due to surgical swelling and the effects of anaesthesia and should be monitored for the first night. According to recent guidelines, clinicians should arrange for overnight, inpatient monitoring of children after tonsillectomy if the child is under three years old or has severe obstructive sleep apnoea (AHI $\geq$10 obstructive events/hour, oxygen saturation nadir $<$80%, or both).

Upper Respiratory Tract Infections (URTIs)

Children requiring ENT procedures often present with mild to moderate URTIs, and the decision whether to proceed with surgery can be difficult. The airway remains hyperreactive over two weeks after a respiratory tract infection and puts the child at increased risk of a PRAE, such as oxygen desaturation, bronchospasm and laryngospasm. Delaying surgery for two weeks after the resolution of systemic symptoms of URTI, such as fever and malaise, is recommended. A pragmatic approach is required, however, and surgery often proceeds despite the presence of mild URTI without systemic symptoms, as the purpose of the operation, such as a tonsillectomy, is to address the underlying cause of the infections or alleviate their consequences. Some steps, such as less instrumentation of the airway and the use of propofol and total intravenous anaesthesia (TIVA), can be taken to mitigate the risk of the two- or threefold increase in PRAE. Propofol induction and TIVA reduces airway reactivity, laryngospasm, bronchospasm and emergence coughing.

SARS COVID-19

There have been several publications with guidelines and recommendations for the perioperative management and planning of ENT care in children during the SARS CoV-2 pandemic (COVID-19). Some ENT procedures carry a high risk of generating aerosols (aerosol-generating medical procedures, or AGMP), which need to be taken into consideration when deciding how to care for the patient and to protect the team. Local policies and procedures, which are usually guided by community prevalence, will dictate how each hospital manages issues such as preoperative testing prior to surgery.

Congenital Anomalies

The commonly encountered congenital, syndromic or genetic anomalies associated with ENT procedures include trisomy 21, craniosynostoses and hemifacial microsomia, children with cleft lip and/or plate and cardiac anomalies. Coagulopathies, although rare, should be considered as they can cause severe morbidity in ENT procedures.

Myringotomy and Grommet Insertion

Myringotomy with or without grommet insertion is a common and quick day-case procedure for the treatment of persistent middle ear effusions (glue ear) and recurrent otitis media.

The usual preoperative assessment should be conducted, paying particular attention to URTIs, which are common in children undergoing this procedure.

Intraoperatively, the airway can usually be maintained with a supraglottic airway device (SAD) with the child breathing spontaneously. Myringotomy can be very stimulating, and this should be pre-empted with a small dose of intravenous opioid, such as 1 mcg kg^{-1} fentanyl IV. Ondansetron and dexamethasone should be used for antiemesis, and IV paracetamol and a non-steroidal anti-inflammatory drug (NSAID) are useful adjuncts for analgesia.

Analgesic requirements postoperatively are variable, but opioids are usually not required.

Adenotonsillectomy

Adenotonsillectomy is the most performed operation in children, and the primary indication is now SDB or OSA rather than recurrent tonsillitis. Surgery is usually undertaken as a day case in

children over the age of three years without other comorbidities.

Standard preoperative assessment should be made with particular attention to the severity of OSA, as discussed in the section 'Obstructive Sleep Disordered Breathing', and screening for high-risk features that might predict a PRAE, which have an estimated incidence of up to 40% in this population. Previous studies have recommended HDU admission for patients with high-risk features, but recent literature does not support this practice. Patients should be assessed in the postanaesthetic care unit (PACU) for signs of airway obstruction, desaturation or prolonged oxygen requirement and then triaged accordingly.

Anaesthesia Management for Children Undergoing Adenotonsillectomy

Children undergoing ENT surgery do not often require preoperative sedation, and it should be used with caution in patients with OSA.

A gas induction is commonly used in younger children. If intravenous induction is planned, topical anaesthetic cream should be applied. The airway may become difficult to maintain in severe OSA, particularly at light planes of anaesthesia. The use of a Guedel airway and the application of continuous positive airway pressure (CPAP) is important and will help to maintain the airway until anaesthesia is deepened. After obtaining intravenous access, the airway can be maintained with an oral south-facing Ring-Adair-Elwin (RAE) tracheal tube (TT), micro cuff endotracheal tube (ETT) or flexible SAD. There are some advantages of using a laryngeal mask airway (LMA), such as less pain postoperatively and improved emergence with less coughing and potential for bleeding. However, there is a greater risk of displacement of the SAD than a TT during surgery, particularly in smaller children. This can be especially problematic at the time of placement of the tonsillar gag, which can obstruct any artificial airway. The anaesthetist must be aware of this and alert the surgeon to any airway concerns. Maintenance can be with volatile or TIVA. TIVA has been shown to decrease postoperative nausea and vomiting (PONV) and may also reduce emergence delirium (ED) and PRAE, although these benefits have not been quantified.

There are several techniques for tonsillectomy, and studies continue to debate which is optimal.

Coblation (cold ablation) is a relatively new and increasingly popular tonsillectomy technique because it is associated with a reduction in postoperative pain and intraoperative bleeding. Coblation is operated at surface temperatures (40–70°C) much lower than those of more traditional techniques, minimising the painful damage of surrounding healthy tissue. This reduces postoperative pain and speeds up recovery. Studies suggest that coblation decreases delayed haemorrhage and postoperative pain and does not worsen intraoperative bleeding and reactionary haemorrhage in children undergoing tonsillectomy compared to the more traditional bipolar technique. Coblation also has improved outcomes with respect to tonsillar tissue recovery, reduced thermal damage, reduced need for analgesia and faster return to normal diet. Bipolar diathermy is another technique that has similar pain and morbidity rates to other tonsillectomy techniques like cold dissection tonsillectomy, but it provides significant advantages such as shorter operative time and lower blood loss levels.

Adenotonsillectomy is a painful procedure usually requiring opioids intraoperatively. Care should be taken in children with OSA as they are more sensitive to the respiratory depressant effects of opioids. Small doses of intraoperative morphine (0.05 mg kg^{-1}) or fentanyl (1–2 mg kg^{-1}) are usually well tolerated. The use of the coblation technique has reduced postoperative pain and made management easier to some extent.

Dual antiemetics of IV ondansetron 0.15 mg kg^{-1} and IV dexamethasone 0.15 mg kg^{-1} are recommended as routine for tonsillectomy and adenoidectomy by the Association of Paediatric Anaesthetists of Great Britain and Ireland. Dexamethasone should be used in all cases unless contraindicated, as there is good evidence for its analgesic properties as well as prophylaxis for PONV.

Analgesia Following Adenotonsillectomy

The management of posttonsillectomy pain can be challenging and is often inadequate. Tonsillectomy has been identified as one of the most painful surgical procedures, and pain remains poorly managed in clinical practice. The degree of pain is often underestimated as the surgery is minimally invasive and pain assessment in children can be difficult. It involves a unique type of tissue trauma, the

exposure of the healing wound to movement of the pharynx during ingestion, the risk of bleeding and limitations in the choice of drugs in children. Despite numerous studies comparing and combining analgesics to find the most effective postoperative regimen, there is still no consensus on the best treatment strategy.

The Procedure-Specific Postoperative Pain Management (PROSPECT) Working Group is an international collaboration of surgeons and anaesthetists working to formulate procedure-specific recommendations for pain management after common but potentially painful operations. The recommendations are based on a procedure-specific systematic review of randomised controlled trials using a standardised methodology. For tonsillectomy, randomised controlled trials published in the English language up to November 2019 assessing postoperative pain using analgesic, anaesthetic or surgical interventions were identified. Approximately one-third (226 of 719) of the potentially eligible randomised control studies met the inclusion criteria.

PROSPECT Recommendations: Analgesia Following Tonsillectomy

- The basic analgesic regimen should include paracetamol and NSAIDs administered preoperatively or intraoperatively and continued postoperatively.
- A single dose of dexamethasone IV is recommended for its analgesic and antiemetic effects.
- Preoperative gabapentinoids, intraoperative ketamine (only in children) and dexmedetomidine are recommended in patients with contraindications to the basic analgesic regimen.
- Analgesic adjuncts such as intraoperative and postoperative acupuncture and postoperative honey are recommended.
- Opioids should be reserved as rescue analgesics in the postoperative period.

Previously, postoperative analgesia included codeine. Its use has stopped due to concern for codeine 'ultra-metabolisers' within the population being overdosed with standard dosing of codeine with resultant apnoea.

There is much interest in the use of dexmedetomidine during adenotonsillectomy to reduce opioid requirements and postoperative emergence delirium. The data are inconclusive. The PROSPECT Working Group identified eight studies concerning IV dexmedetomidine in paediatric patients. Any analgesic benefit is unclear, but none of these studies assessed the benefit of adding dexmedetomidine on top of a basic analgesic regimen. Dexmedetomidine was associated with less agitation after sevoflurane-based anaesthesia in two studies.

Postoperative Management Following Adenotonsillectomy

In children with severe OSAS, a nasopharyngeal airway can be inserted by the surgeon under direct vision at the end of surgery before the child is woken up. Keeping this in situ for the first postoperative night helps to bypass upper airway oedema caused by surgery. This is particularly helpful in syndromic children and children with sickle cell disease. The use of NPAs has reduced the requirement of postoperative paediatric intensive care unit (PICU) in children with severe OSA and complex comorbidities.

Postoperative Complications Following Adenotonsillectomy

Nine per cent of children less than four years old have an unplanned admission following adenotonsillectomy, commonly because of vomiting. Postoperative primary haemorrhage (within six hours) is uncommon but is a life-threatening complication requiring emergent operative management with considerations that include full stomach, soiled airway and hypovolemic shock.

Intravenous access must be left in place in case of immediate postoperative bleeding. Early signs of important blood loss include:

- Pallor
- Slow capillary refill (>1 second)
- Tachycardia

Restlessness, confusion and hypotension are late signs and suggest significant blood loss. Large amounts of blood may be swallowed, leading to an underestimate of losses. A full blood count, clotting screen and blood cross-match should be performed. Ideally, fluid resuscitation should be undertaken before returning to theatre to mitigate the effect of anaesthesia in a hypovolaemic child.

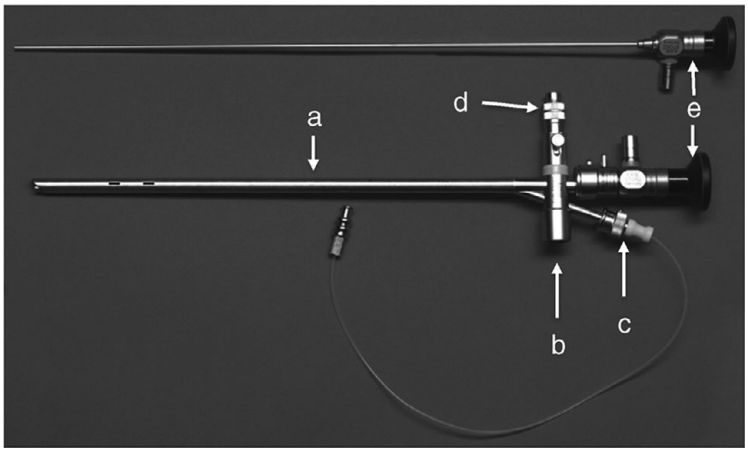

Figure 21.1 Storz ventilating bronchoscope and Hopkins rod. Notes:
(a) Centre channel, through which Hopkins rod can be passed.
(b) Port for anaesthetic gas flow; (c) suction channel; (d) light source attachment; (e) Hopkins rod. The lower image shows the bronchoscope with the Hopkins rod inserted.

In addition to hypovolaemia, anaesthesia is problematic because the child may have a stomach full of blood and active bleeding may make laryngoscopy and intubation difficult. There is little agreement on the safest technique of anaesthesia for a bleeding tonsil, and the anaesthetist should use the technique they are comfortable with. A rapid sequence induction with pre-oxygenation and cricoid pressure is advocated by some, whilst others prefer an inhalational induction with sevoflurane in oxygen, starting in a head-down, lateral position.

During the operation, further fluid and blood should be given as required, and near patient testing can help guide transfusion requirements. Before termination of anaesthesia, a wide bore orogastric tube can be passed to empty the stomach. Extubation should be in a lateral, head-down position with the child awake.

Diagnostic and Therapeutic Endoscopy

Diagnostic and therapeutic microlaryngoscopy and bronchoscopy (MLB) is an important part of paediatric ENT surgery. It allows visualisation of the larynx, trachea and proximal bronchi. The indications include, but are not limited to, patients with stridor, unresolving and recurring pneumonitis, persistent atelectasis, persistent cough, tracheoesophageal fistula, airway trauma, tumours and suspicion of foreign body.

MLB may involve the use of a suspension laryngoscope and operating microscope or more commonly a Storz ventilating bronchoscope (Figure 21.1) with a Hopkins rod telescope that is passed through it.

Diagnostic Endoscopy

MLB is often performed in children with mild to moderate airway obstruction.

An understanding of the likely pathology and the underlying medical condition helps to optimise anaesthesia for these investigations, which can be challenging at times. Many common abnormalities of the paediatric airway are dynamic (e.g. laryngomalacia, tracheomalacia and vocal cord palsy). To make a diagnosis, the surgeon needs a larynx that is still and unobstructed by a tracheal tube, with the patient breathing spontaneously. The depth of anaesthesia may need to be varied rapidly, as accurate assessments of dynamic pathology need the patient to be almost awake but not coughing or prone to laryngeal spasm.

Preoperative Preparation

Signs of upper airway obstruction include stridor, sternal depression and/or indrawing of the supraclavicular, intercostal and subdiaphragmatic areas. These signs are evident when the airway is significantly reduced (by 70%) and can be magnified because of the very compliant chest wall in infants. Inspiratory stridor indicates obstruction at or above the larynx whilst hoarseness suggests vocal cord involvement. Biphasic stridor (inspiratory and expiratory) is heard with obstruction above or below the vocal cords. Expiratory stridor alone is a symptom of intrathoracic obstruction.

The preoperative investigations required are determined by history and examination and may include chest X-ray, lateral neck X-ray, barium swallow and echocardiography. Previous tracheal intubation may have given rise to airway pathology such as cricoarytenoid fixation, subglottic

stenosis (SGS) or tracheal stenosis, whilst surgery may have resulted in injury (e.g. recurrent laryngeal nerve palsy during ligation of a patent ductus arteriosus). A full medical history should be obtained, as children with airway pathologies often have complex histories and may have undergone many medical interventions.

Historically, patients have been premedicated with an anticholinergic agent with the idea that reduction of secretions may reduce the incidence of coughing, breath-holding and laryngospasm. There are no data to support this, and this practice is no longer considered essential.

Anaesthesia

The challenge for anaesthetists is maintaining adequate depth of anaesthesia without tracheal intubation whilst avoiding apnoea, hypoxaemia and hypercapnia, often in children with comorbidities and complex medical histories.

The onset of oxygen desaturation during endoscopy is age dependent. Virtual modelling of healthy children who were 1 month, 1 year, 8 years and 18 years has shown that oxygen desaturation occurs in the order of age, with the 1-month-old neonate desaturating first, followed by the 1 year old, 8 year old and then the 18 year old. This modelling was conducted with open and obstructed airways, and repeated with preoxygenation periods of 0, 1 and 3 minutes. The rate of oxygen desaturation from 90% to 40% was approximately the same for all ages (~33%/minute for an obstructed airway, and ~26%/minute for an open airway). Preoxygenation delayed the onset of oxygen desaturation in all age groups, but the benefit of preoxygenation was least in the one-month neonate. In the absence of preoxygenation and an open airway, a one-month-old neonate desaturated in only 6.6 seconds compared to 33.6 seconds for the eight-year-old child. This difference can be explained by the physiology of the neonate, as they have a larger minute ventilation to functional residual capacity (FRC) ratio, a high metabolic rate and low maximal SaO_2 compared to older children.

Induction of Anaesthesia

Sevoflurane in 100% O_2 is commonly used for gas induction. Nitrous oxide can be used in carefully selected patients as the second gas effect can be helpful to speed up the process of gas induction. It is important to maintain spontaneous respiration during induction and maintenance of anaesthesia in children with airway obstruction. Muscle relaxants should be avoided until reliable bag mask ventilation is possible.

In children with severe airway obstruction, it can be challenging to undertake a gas induction and maintain anaesthesia with inhalational agents as the obstructed airway can impede the delivery of the inhalational agent. Induction can be slow and particularly difficult in lighter planes of anaesthesia when obstruction can become worse due to reduction of tone in the airway. The author prefers to have IV access in situ in difficult cases so anaesthesia can be rapidly deepened if necessary and/or other rescue medication can be administered rapidly. Traditionally, IV induction has been avoided in airway obstruction for fear of apnoea and subsequent difficulty in maintaining or establishing an airway. However, careful and judicious use of IV agents like propofol does not necessarily result in apnoea and has the benefit of separating the mode of delivery of anaesthesia from the area of pathology, the obstructed airway. In addition, propofol and TIVA are associated with reduced airway complications and smoother wake-up.

CPAP is often required to maintain the airway and oxygenation once the child with the obstructed airway is anaesthetised. Positive pressure helps to overcome the loss of tone after induction of anaesthesia and splint the airway open. It is particularly important in smaller infants and babies where tidal breathing can impinge on FRC, resulting in relatively rapid airway collapse and desaturation. It can take several minutes to deepen anaesthesia so that laryngoscopy can be tolerated in a child with an obstructed airway using an inhalational agent alone. If not already in situ, intravenous access is obtained as rapidly as possible. The cords are sprayed with topical anaesthesia. There is a risk of laryngeal spasm if spray is attempted at an inadequate depth of anaesthesia, so depth of anaesthesia should be carefully assessed before this is attempted. It can be helpful to administer a small bolus of propofol pre-spray to prevent laryngospasm. Lidocaine (to a maximum of 5 mg kg^{-1}, or 160 mg) is sprayed onto the glottis, vallecula and trachea. The author prefers to limit the dose of lidocaine used around the larynx to 2 ml of 1% lidocaine. This seems to be as effective as higher doses and concentrations of lidocaine as the cords are exquisitely sensitive to topical lidocaine application. Using a low dose of lidocaine on the cords means that additional lidocaine can be used elsewhere in the

airway if necessary, such as around the carina, whilst remaining within safe dose limits. A nasopharyngeal airway, usually a RAE tube half a size smaller than a tube suitable for the airway, is passed through the nose into the posterior pharyngeal space, ideally under the same laryngoscopy as the cord spray. This is used to supply oxygen and/or inhalational agent to maintain anaesthesia. One hundred per cent oxygen is used to maintain oxygenation. The risks of desaturation can be significant, particularly in babies where oxygen consumption is high and FRC is reduced, resulting in decreased oxygen storage capacity. The author's preference is to maintain anaesthesia using TIVA, as this separates delivery of anaesthesia from the airway, which can be frequently compromised. It requires some experience to avoid hypoventilation or apnoea, but the airway is easier to manage once this technique has been perfected. Close monitoring is essential to detect hypoxia and hypoventilation as well as excessively light anaesthesia. At the end of the examination, anaesthesia is stopped, 100% oxygen is continued and the larynx is observed until the patient is virtually awake.

Maintenance of Anaesthesia

Anaesthesia can be maintained using inhalational agents namely sevoflurane or TIVA or a combination of both. TIVA, with a combination of propofol (200–400 mcg kg^{-1} min^{-1}) and remifentanil (0.05–0.15 mcg kg^{-1} min^{-1}) by infusion, or propofol and alfentanil by intermittent injection. Using TIVA means that the maintenance of anaesthesia is independent of the airway, which is an advantage where intermittent obstruction by the surgeon can lead to light anaesthesia and patient movement. TIVA also usually results in a better recovery than with volatile agents, particularly in children over two years, but should be used with caution if there is concern that the airway cannot be adequately maintained (although in the author's experience this is very unusual).

Intermittent boluses of propofol and alfentanil by hand (propofol 10–20 mg kg^{-1} h^{-1} and alfentanil 20–30 mcg kg^{-1} h^{-1}) can be very effective, as it allows rapid titration of anaesthesia to the stimulus being applied. It does require careful observation of the surgical procedure and awareness of the requirements of different interventions. For example, balloon dilation of the trachea is very stimulating, and it is difficult to avoid coughing. Application of topical lidocaine can be helpful, using a pre-emptive bolus of propofol with alfentanil. Too much IV agent can result in apnoea, and if there is desaturation the surgery will have to be stopped. The anaesthetist and surgeon should be prepared for this eventuality, and tracheal tubes of various sizes should be available and ready to be placed urgently if desaturation occurs.

As oxygenation is so critical and at times challenging, alternative forms of oxygenation have been sought. Transnasal humidified oxygenation and ventilatory exchange (THRIVE) has been used as an adjunct in airway surgery, and in the appropriate population group can allow improved oxygenation and surgical conditions using flow rates of 2 l $kg^{-1}min^{-1}$. The Optiflow (Fisher and Paykel Healthcare™) is a heated humidified high-flow delivery system. The nasal cannulas are specifically designed for this purpose, to withstand high flows of gas. The cannulas are made of soft silicon and are designed with skin applicators for the face to improve patient comfort during prolonged use. Adult flow rates of 70 l min^{-1} have been described for THRIVE. Recommended paediatric flow rates appear in Table 21.1.

An early report of 20 infants less than three months old undergoing tracheal intubation with Optiflow™ found that the benefit seemed to depend on whether the child was sick or healthy. Oxygen saturation remained normal throughout the intubation for 12 healthy children with normal lungs, but five of the eight sick children desaturated. The use of Optiflow™ during paediatric anaesthesia is still novel compared to the extensive experience in paediatric intensive care. Potential applications during paediatric anaesthesia might include Optiflow™ for preoxygenation, tracheal intubation, laryngeal and other upper airway surgery, endoscopy and anaesthesia recovery.

Table 21.1 Suggested flow rates for children receiving heated humidified high-flow nasal cannula (HHHFNC) oxygen/air (personal communication from Associate Professor Andreas Schibler, Mater Research Institute, University of Queensland, Brisbane, Australia)

Weight (kg)	Flow rate (l kg^{-1} min^{-1})
0–15	2
	Flow rate (l min^{-1})
> 15–30	35
> 30–50	40
> 50	50

Apnoeic Oxygenation

There is much interest in the use of apnoeic oxygenation for MLB to optimise oxygenation and operating conditions. The concept of delivering oxygen to apnoeic patients was first described by Holmdahl in 1956. It was recognised that, during apnoea, oxygen is taken up by the blood from the FRC at a rate that exceeds the outflow of carbon dioxide. This occurs because of the relatively high solubility of carbon dioxide in the blood. Flow rate differential then occurs between oxygen removal from the alveoli and carbon dioxide excretion. This generates a negative pressure gradient of –20 cm H_2O, creating bulk flow of oxygen from the upper airway to the alveoli. Oxygen can be delivered from the nose, face mask, pharynx or trachea at varying flow rates and inspired concentrations. However, the effectiveness of apnoeic oxygenation varies depending on the delivery technique and the age and physical status of the patient. With preoxygenation and apnoeic oxygenation through a tracheal tube, normal oxygen saturations can be maintained for 10 minutes in children, but infants may desaturate after only 3 minutes of apnoea. In a study by Cook et al. of 28 children and infants, PaO_2 decreased at 4.1 kPa min^{-1} or 30 mmHg, which is three times faster than an adult. A similar study by Kernian et al. demonstrated that, after preoxygenation and apnoeic oxygenation with 0.1 l kg^{-1} min^{-1} through a tracheal tube, oxygen desaturation was prevented for 3 minutes. In a control group breathing air, oxygen desaturation occurred after 116 seconds in patients who were 3–10 kg; 147 seconds if weight was 10–20 kg and 217 seconds if the child weighed >20 kg.

A limitation of this technique is the steady increase in $PaCO_2$ of 0.4–0.8 kPa min^{-1} due to absent ventilation and clearance of carbon dioxide. Over time, this can cause respiratory acidosis and an associated spectrum of complications.

Diagnostic Bronchoscopy

Most diagnostic ENT bronchoscopies are undertaken using the Hopkins rod, and anaesthesia continues as described in the preceding sections. If a full bronchoscopic examination is needed, a Storz ventilating bronchoscope is used. A side arm allows attachment of an anaesthetic T-piece for administration of 100% oxygen with or without volatile agent (see Figure 21.1). Once the Hopkins rod is in place, a closed system exists, allowing ventilation to occur in the annular space between the telescope and the surrounding bronchoscope. A suction catheter can also be passed through another side arm on the instrument. Resistance is high in the smaller bronchoscopes, significantly increasing the work of breathing, particularly for infants. Furthermore, resistance increases with the length of the instrument; at 3 l min^{-1} flow rates, the resistance of a 30 cm 3.5 bronchoscope is four times that of a 20 cm model. Assisted ventilation may be needed, especially for infants. Resistance to expiration is high, and air trapping can occur unless a long expiratory phase is employed. It may be necessary to remove the telescope temporarily and allow unobstructed ventilation through the empty bronchoscope.

Fibreoptic endoscopy can be used in the diagnosis of upper airway obstruction, more commonly by respiratory physicians or interventional radiologists. Anaesthesia is best conducted with a SAD or face mask using a bronchoscopic swivel mount, which has a small self-sealing hole through which the fibrescope is passed. A diagnostic bronchogram may be performed at the same time.

Complications during Bronchoscopy

The most common complications are related to oxygenation and ventilation. Frequently patients may become hypoxic or hypercapnic, which may lead to bradycardia, cardiac arrhythmias and arrest. Barotrauma can occur (e.g. pneumothorax, pneumomediastinum) from inadequate egress of air from insufflation of oxygen during bronchoscopy. Introduction of the laryngoscope, the Hopkins telescope or bronchoscope can damage the teeth, gingiva or surrounding soft tissue. Downward force should not be placed onto the maxillary teeth with the bronchoscope.

When passing the bronchoscope, gentle manoeuvring around the soft tissue of the posterior pharyngeal wall and epiglottis is important to avoid laceration and/or laryngeal fracture. In addition, there may be damage to the arytenoids or vocal folds when traversing this area. Ensuring that the bronchoscope passes through abducted vocal cords, posteriorly and at a 90-degree angle can help to minimise laryngeal trauma. Placing the bronchoscope into the subglottic region and trachea can trigger a vagotonic response and

bradycardia, which is typically more pronounced in children <6 months of age.

Significant trauma from the bronchoscope itself or from the therapeutic intervention could potentially induce a pneumothorax. If a pneumothorax is suspected, all operating room staff should be made aware of the situation and a chest drain inserted, the urgency of which will be determined by the condition of the child.

Loss of Airway during Diagnostic Investigation

On occasion the loss of tone associated with the onset of anaesthesia may result in airway decompensation, requiring CPAP to preserve respiration. This manoeuvre may be insufficient, especially in patients with small and/or obstructed airways. An array of tracheal tubes of varying sizes should be readily available in case of emergency. In extremis, a tracheal tube can be loaded onto the Hopkins rod and the surgeon can intubate under direct vision. The key is to be very vigilant and proactive and to not let saturations drop below a predetermined level (e.g. 95%) before intervention is undertaken. This is particularly important in babies and small children who have limited oxygen reserves and high oxygen consumption. Many patients undergoing these investigations or interventions are ex-prems or children with recurrent aspiration who may have poor lung function. Constant vigilance and a proactive approach are key to prevent desaturations.

Specific Conditions Identified by Diagnostic Endoscopy or Bronchoscopy Laryngomalacia

This is the most common cause of stridor in infancy. Stridor can be present within a few days of birth but rarely requires immediate intervention. Infants may have inspiratory stridor with marked sternal recession and tracheal tug. Feeding difficulties are common in more severe cases. The airway obstruction is due to collapse of the supraglottic structures on inspiration. The natural history of the condition is to resolve by two years of age, but in severe cases with marked stridor, recession and impaired growth due to feeding difficulties, surgery to divide the aryepiglottic folds or remove excess arytenoid mucosa can be undertaken and is usually successful. This is performed after airway examination under spontaneous ventilation with oxygen delivered either via a nasopharyngeal airway or via the suspension laryngoscope and anaesthesia provided by TIVA/target-controlled infusion (TCI).

Tracheomalacia and Tracheobronchomalacia

These conditions cause collapse of the airway on expiration. Symptoms may be intermittent and include expiratory wheeze, stridor and severe episodes of cyanosis and reflex apnoeas sometimes called 'dying spells'. The presentation is usually during the first year of life. It may be due to underlying deficiency or weakness of the tracheal rings, caused by extrinsic compression commonly from a vascular anomaly, or seen in babies after repair of tracheooesophageal fistula. Diagnosis is made by bronchoscopy and/or bronchogram with spontaneous ventilation maintained. The level of positive end expiratory pressure (PEEP) required to maintain airway patency can be measured during the bronchogram. In the acute situation, airway management is not usually difficult, and positive pressure ventilation stabilises the child.

Surgical options depend on the aetiology of the problem and include correction of the vascular anomaly, aortopexy or, occasionally, airway stenting. In the case of cartilaginous weakness, prolonged positive pressure airway support may be needed, sometimes via a tracheostomy.

Vocal Cord Palsies

These may be present from birth or develop after thoracic surgery or neurological injury. Unilateral cord palsy often causes relatively mild symptoms of stridor and a whispery cry but may be a cause of failed extubation after cardiac surgery. Bilateral cord palsy will cause much more severe symptoms of stridor with marked sternal recession and tracheal tug. If acute intervention is required, PEEP applied during induction acts as a dynamic splint to maintain a wider airway. Treatment options depend on the severity of symptoms; tracheostomy may be required for bilateral vocal cord palsy.

Therapeutic Endoscopy

A wide range of therapeutic operations can be performed on the airway, often in patients with significant airway obstruction. Maintenance of anaesthesia by volatile agents or TIVA, as described previously, is indicated. Paracetamol and a NSAID should be given as analgesia.

CO_2 laser is rarely used in the paediatric airway due to an increased propensity to scarring in the airway. The usual precautions for the use of a potassium titanyl phosphate (KTP) laser should be undertaken. The inspired oxygen concentration should be reduced when using the KTP laser to reduce the risk of airway burns. Laser surgery should only be undertaken in properly equipped theatres, and all staff should wear appropriate eye protection. Viral papillomas are occasionally lasered. High-volume theatre air scavenging is important, as vaporised viral particles may be released, and theatre staff should wear masks.

Specific Conditions Treated by Therapeutic Endoscopy Laryngeal Papillomas

These are benign proliferations of squamous epithelium usually caused by the human papilloma virus types 6 and 11. The usual site is the larynx, but they can occur anywhere in the tracheobronchial tree (see Figures 21.2 and 21.3). The onset of symptoms is often very slow, with progressive dyspnoea sometimes treated as asthma and hoarse voice or aphonia. These children usually require anaesthesia as a planned procedure for airway investigation or for surgery but may present acutely with severe respiratory distress and stridor with an airway almost completely obstructed by florid cauliflower-like growths.

Anaesthesia can be induced using gas or slow IV injection, which has the advantage of separating the anaesthesia from the obstructed airway. This makes induction more predictable, but it should be undertaken slowly and with caution so that spontaneous ventilation is maintained. The treatment is by surgical debulking usually with spontaneous ventilation, so topical lidocaine is required. Intubation is avoided if possible to reduce the chance of seeding papilloma further down the airway.

Anaesthesia is maintained either with gas via a nasopharyngeal airway or with TIVA. Adjuvant treatments such as intralesional injections of the anti-viral cidofovir are sometimes used.

The condition is recurrent in some cases, requiring numerous procedures over many years to maintain an airway. Afflicted children are often distressed because of repeated general anaesthetics and may require premedication despite some airway compromise. In future, countries where the quadrivalent human papilloma virus vaccine is given to prevent cervical cancer could see a significant reduction in the incidence of laryngeal papillomatosis.

Airway Cysts

Congenital supraglottic cysts are uncommon but may present with stridor from birth, sometimes requiring immediate intervention. Although at times very large, they are fluid filled and compressible and can sometimes be pushed aside by a tube

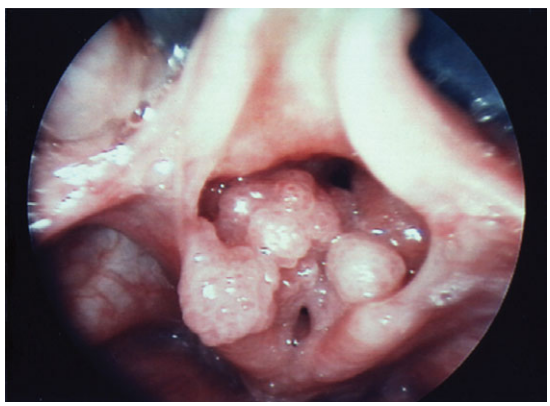

Figure 21.2 Laryngeal papillomas causing partial airway obstruction.
Source: With thanks to Dr S. Bew.

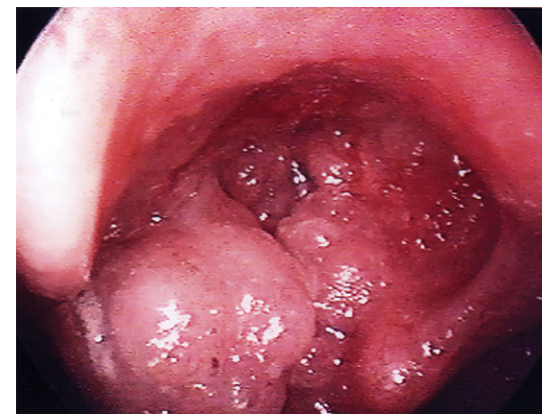

Figure 21.3 Laryngeal papillomas causing severe airway obstruction.
Source: With thanks to Dr S. Bew.

with a stylet allowing intubation. Occasionally the whole larynx is obscured, and the cyst may need aspiration under direct laryngoscopy to reveal the larynx. The cysts are then marsupialised to prevent recurrence.

Subglottic cysts are usually seen in infants who have been intubated previously, often as neonates. They probably result from subglottic trauma, although the period of intubation does not need to be prolonged. These infants may present with biphasic stridor or audible harsh breathing sounds and respiratory distress several months after discharge from the neonatal unit. Subglottic cysts can be excised using grabbing forceps and/or sickle knife.

Postanaesthesia Care

Meticulous observation in the PACU is essential following diagnostic or therapeutic endoscopy. Airway oedema because of intervention or instrumentation is common, and children may develop respiratory distress with stridor on recovery. All patients undergoing therapeutic endoscopy and those in whom instrumentation may have been difficult should receive dexamethasone (250 mcg kg^{-1} initial dose, thereafter 100 mcg kg^{-1} 8 hourly).

Stridor in the PACU may also require nebulised adrenaline (1:1,000, 5 ml). The ECG should be monitored during administration of nebulised adrenaline, which should be stopped temporarily if the heart rate is >190 beats per minute.

Airway Emergencies

Acute Airway Emergencies

The most common infective conditions are acute viral laryngotracheobronchitis (croup), acute epiglottitis and bacterial tracheitis.

Epiglottitis

The incidence of this condition fell steeply in 1992 after the introduction of routine vaccination against *Haemophilus influenzae type b* and is now only seen very occasionally in unvaccinated children, in cases of vaccine failure or when other organisms cause epiglottitis. Epiglottitis presents with rapidly progressive fever, dysphagia, drooling, tachypnoea and stridor, typically in children between one and six years of age. Classically these children adopt a tripod posture, leaning forward on their hands to maintain their airway.

The child can be toxic and very unwell and should be kept in a comfortable position with oxygen delivered as tolerated, which is often more effective with the parent holding the mask. The child should be kept as calm and comfortable as possible, as distress can result in further airway compromise. Nebulised adrenaline may reduce swelling and improve the chance of successful intubation. Anaesthesia can be by gas or very slow IV induction with the child in the sitting position. Spontaneous ventilation should be maintained. The larynx may be very difficult to identify with all supraglottic structures red, swollen and distorted (see Figure 21.4). The movement of secretions or a bubble of gas from the larynx may help identification. Intubate with a tube smaller than expected for age. The child should remain intubated on PICU until a leak develops round the tube.

Croup or Laryngotracheobronchitis

This is an upper respiratory infection usually caused by the parainfluenza virus. Symptoms are slower in onset than in epiglottitis and are characterised by a barking cough.

The subglottis is narrowed by swelling, which can be seen on an anterior-posterior neck X-ray as a loss of the normal shouldered appearance of the air column, giving the appearance of an inverted *V* known as the steeple sign (see Figure 21.5).

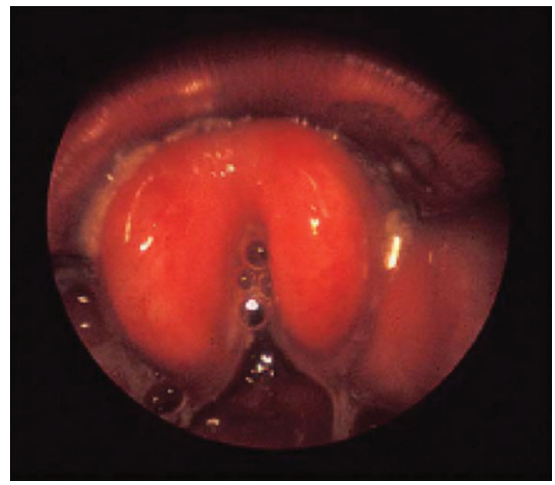

Figure 21.4 Endoscopic view of the epiglottis in epiglottitis. *Source:* Reprinted from Hammer J. Acquired upper airway obstruction. *Paediatric Respiratory Review* 2004; 5:29, with permission from Elsevier.

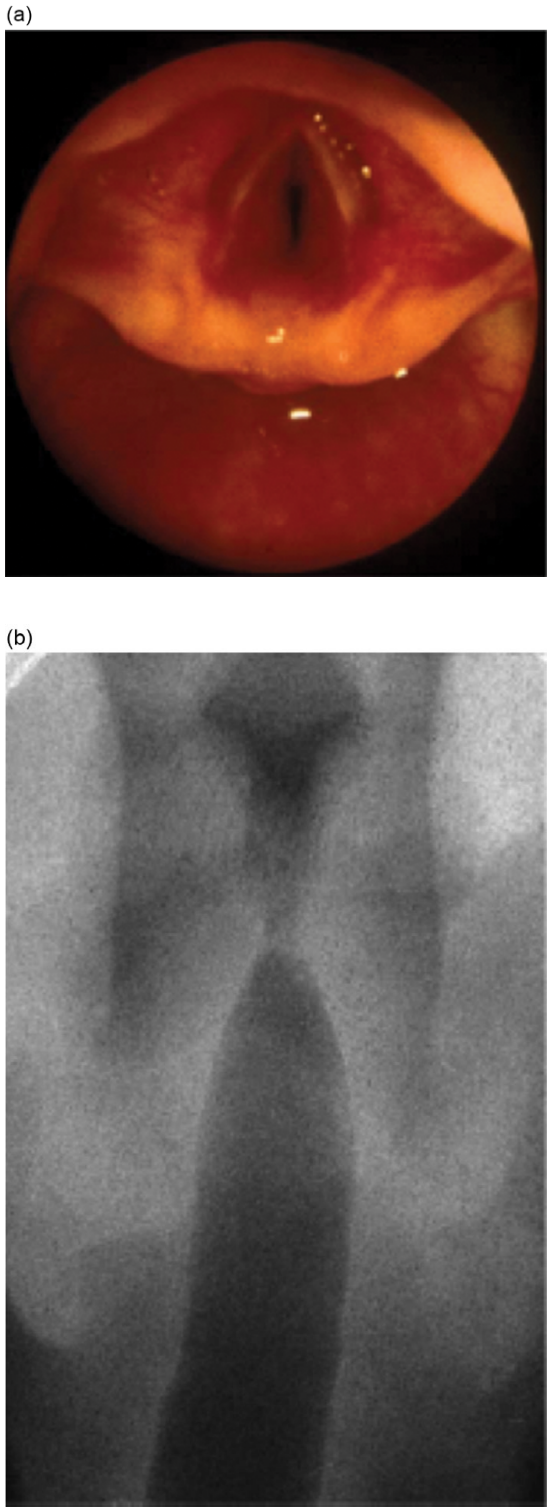

Figure 21.5 Endoscopic view of the larynx in croup (a). Radiological presentation of subglottic oedema in viral croup (b), compared with normal (c).
Source: Reprinted from Hammer J. Acquired upper airway obstruction. *Paediatric Respiratory Review* 2004; 5:26, with permission from Elsevier

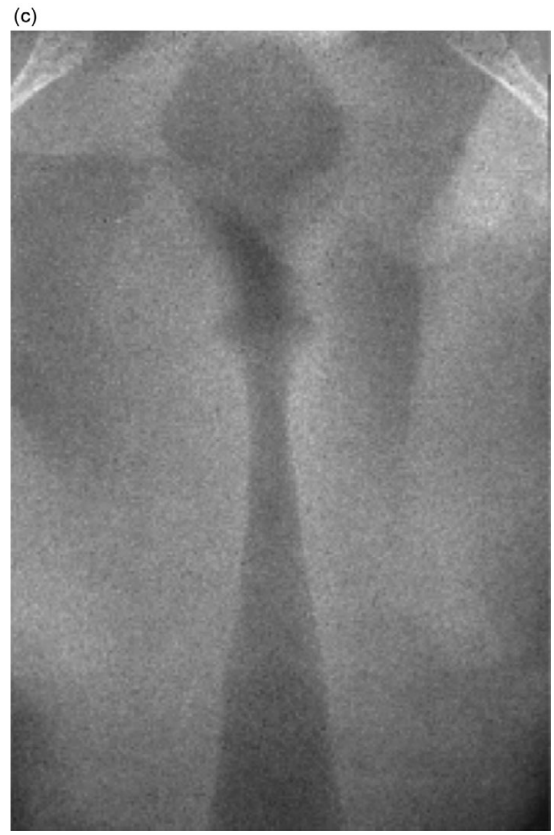

Figure 21.5 (*cont.*)

Mild croup is common in the winter, but only a very small proportion of cases require hospital admission. Most respond to medical treatment with inhaled budesonide or intravenous dexamethasone and nebulised adrenaline. Humidification of inspired gases is also widely used. A small number of children do not respond to medical treatment and gradually deteriorate, becoming exhausted and requiring intubation.

Although there will be inflammation of the supraglottic tissues and excess secretions, the laryngoscopy is not usually difficult, although a smaller tracheal tube than expected for age will be needed.

Bacterial Tracheitis or Pseudomembranous Croup

In some centres, this is now a more common cause of PICU admission than croup. The initial presentation is often croup-like, but the child is toxic and rapidly deteriorates with cough, fever and stridor. An anteroposterior (AP) neck X-ray may also show the 'steeple' sign. The most common organism is

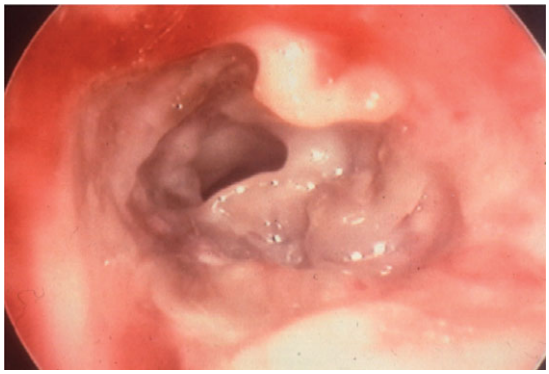

Figure 21.6 Endoscopic view of the trachea in bacterial tracheitis.

Staphylococcus aureus, which causes inflammation and thick mucopurulent secretions (see Figure 21.6). The tracheal tube may become obstructed by secretions or sloughing of the tracheal epithelium, and the child will require frequent suctioning or occasionally rigid bronchoscopy to remove the pseudomembranes. The course on PICU may be complicated by sepsis and pneumonia, and the duration of intubation is usually longer than in croup.

Retropharyngeal Abscess

This is caused by lymphatic spread of infection from sinuses, teeth or middle ear into the space between the posterior pharyngeal wall and the prevertebral fascia. It is mainly seen in young children and presents with fever, sore throat, neck pain and swelling with limitation of movement and drooling. These children are usually stable enough for a CT scan. Larger abscess collections will require surgical drainage.

Stridor is not often a major feature, but the intubation can be very difficult, with copious secretions and tissues distorted by the bulging pharyngeal wall.

Attempts to pass a tube or bougie can rupture the abscess, with the risk of airway soiling and the laryngeal view becoming obscured by purulent secretions.

Removal of an Inhaled Foreign Body

Inhalation of a foreign body usually occurs between the age of one and three years; it is more common in males. The episode is often witnessed; an episode of choking is usually followed by a bout of coughing. Hoarseness and/or stridor suggest that the foreign body is impacted in the larynx, whereas passage into the trachea or main bronchi may cause wheeze or unilaterally reduced breath sounds. Rarely, an object causes a complete glottic or subglottic obstruction, which is rapidly fatal. Partial obstruction is caused by objects lodged in or around the laryngeal inlet. The initial choking or coughing episode is followed by biphasic stridor and a change in the voice or cry, which may become hoarse. An object with sharp edges may cause pain on swallowing, causing infants to drool. Most children will present immediately with marked respiratory distress.

If it is radio opaque, the foreign body may be seen on chest X-ray (CXR), but the majority are radiolucent. Inspiration and expiration films are required as hyperinflation may be seen on the affected side, but a normal CXR does not exclude the diagnosis. In later presentations, collapse and consolidation may be seen distal to the obstruction.

The approach to anaesthesia is as for diagnostic bronchoscopy. Atropine premedication, gaseous induction using oxygen and an inhalational agent with topical anaesthesia are satisfactory. If there is respiratory distress, urgent bronchoscopy is indicated; otherwise, the procedure should wait for an appropriate starvation period. A smooth technique using deep anaesthesia and avoiding coughing is essential. Intubation should be avoided if the foreign body is in or near the larynx, whilst positive pressure ventilation is best avoided if the foreign body is in the trachea or creating ball-valve obstruction. A 30 cm ventilating bronchoscope with Hopkins rod and grasping forceps is used. Application of topical adrenaline (1:10,000) to the area of impaction is useful to reduce oedema and facilitate removal of the foreign body.

Ventilation may need to be gently assisted if the bronchoscope is in a main bronchus for a prolonged period. Side holes in the Storz bronchoscope assist proximal ventilation. Once the object is firmly grasped in the forceps, the whole instrument is slowly removed from the airway under vision, ensuring that the foreign body does not fall out of the forceps. Once the bronchoscope has been removed, anaesthesia is maintained by mask whilst awaiting reinsertion of the bronchoscope to confirm full removal. When withdrawing the bronchoscope with the foreign body, the danger is loss of the object either in the trachea or larynx, which may cause total obstruction to ventilation.

Should this occur, the bronchoscope should be reinserted to push the object into the distal airway so that satisfactory ventilation can be re-established.

Choanal Atresia

Choanal atresia is a membranous or bony occlusion of the posterior nares with an incidence of 1:8,000 births. It may be unilateral, when presentation is often delayed. Bilateral obstruction causes acute respiratory distress in neonates as they are obligate nasal breathers. An oral airway and an orogastric tube should be inserted and taped to the face, whilst surgery is undertaken within 24 hours. Other anomalies are common (e.g. CHARGE syndrome), and thorough preoperative assessment including echocardiography is needed.

In choanal atresia, surgery involves dividing the membrane obstructing the posterior nares. Where there is bony occlusion, a passageway is drilled, and this can cause significant bleeding despite intraoperative use of topical adrenaline. There should be a preoperative group and save serum. A standard technique for neonatal anaesthesia can be used, with muscle relaxant, tracheal intubation (RAE tracheal tube), positive pressure ventilation and analgesia (paracetamol and fentanyl). A throat pack is not used as it will obstruct the surgical view. Patency of the new nasal passageway is ensured by the insertion of nasopharyngeal stents made from standard tracheal tubes. These require regular suctioning and are left in situ for eight weeks. Restenosis is common, and patients may return for further surgical correction.

Anaesthesia for Tracheostomy

Tracheostomy is indicated for congenital or acquired airway obstruction, to facilitate long-term respiratory support or in the presence of a neurological abnormality. Anticholinergic premedication can be useful if there are a lot of secretions. Inhalational induction can be with sevoflurane in oxygen or a slow IV induction used. Relaxants should be avoided unless reliable manual ventilation can be achieved. Some patients (e.g. those with Pierre Robin sequence) may be impossible to intubate. In these patients, anaesthesia is maintained using oxygen, a volatile agent and spontaneous respiration or judicious use of TIVA whilst the airway is maintained using an LMA or face mask.

Once the airway is secured, muscle relaxants, positive pressure ventilation and a volatile agent can be given. Respiratory obstruction may occur during surgery, and hand ventilation permits early detection. The patient is positioned with the head extended using a sandbag under the shoulders; strapping is passed around the chin and secured to the operating table, thereby stabilising the head. Lidocaine 1% and 1:200,000 adrenaline is infiltrated at the site of incision in the neck, and the trachea is identified by dissection. The second and third tracheal rings are identified, and two stay sutures are inserted, one on either side of the planned tracheal incision. These sutures are taped to the chest at the end of the operation and are not removed until the first tube change at one week. They are vital for postoperative safety; if the tracheostomy tube falls out, these sutures are used to pull the trachea to the surface to facilitate tube reinsertion.

Before the tracheal incision is made, 100% oxygen is given and the proposed tracheostomy tube and connector is checked. Standard tracheostomy tubes (Portex, Shiley or Bivona) with 15 mm connectors are used. Once the trachea has been incised, the tracheal tube is withdrawn into the upper trachea and the tracheostomy tube is inserted. The anaesthesia circuit is connected, and ventilation is checked by auscultation of the chest and capnography to confirm correct placement of the tracheostomy tube. At the end of surgery, the head is taken out of extension, and tracheostomy tapes are passed around the neck to secure the tube.

Postoperatively, a CXR is taken to confirm correct tube placement and to exclude a pneumothorax. Warmed humidified air/oxygen, using elephant tubing and tracheostomy mask, is given to neonates and infants; cold humidity is used for older children. This is combined with regular sterile suctioning with saline irrigation (1–2 ml) to ensure that crusting and blockage do not occur. A spare tracheostomy tube, tapes and dilators are kept with the patient. Humidification can usually stop after the first tube change, and a 'Swedish nose' is used instead.

Open Operations on the Larynx

Subglottic Stenosis (SGS)

This may be congenital, but more often develops postintubation and can occur at any age after even

a brief period of intubation. Children may present with biphasic stridor, dyspnoea on exertion and croupy cough, or after failed extubation in the PICU. In some patients, the symptoms and signs may be very subtle. An infant who is not yet mobile may show only minimal subcostal recession and, rather than stridor, have soft biphasic respiratory sounds.

It is important to maintain spontaneous ventilation whilst the airway is assessed under anaesthesia, as it may be extremely difficult to ventilate through a very narrow airway, and the high pressures cause gastric distension. If intubation is required either to secure a safe airway or for a tracheostomy, it can be very difficult to pass a tube. It may be possible to pass a straight 5 Fr bougie and corkscrew in a size 2 tracheal tube, but at times even this is too big. A Cole tube is more rigid and may be useful in this situation. Repeated attempts to pass a tube will rapidly lead to oedema and worsening obstruction. A tracheostomy should be performed whilst spontaneous ventilation and face mask anaesthesia is still possible. Definitive treatment of SGS is by anterior cricoid split, laryngotracheal reconstruction or cricotracheal resection.

Anterior Cricoid Split

This operation is used in children with SGS, often those unable to be extubated in the PICU but who are otherwise well with no pulmonary disease. Head positioning is the same as for a tracheostomy; the trachea is dissected, after which the cricoid cartilage and the first and second tracheal rings are divided in the midline anteriorly. Anaesthesia with tracheal intubation, a muscle relaxant, opioid and ventilation by hand is appropriate. Following the split, a nasotracheal tube of a larger size is passed with the tube tip positioned just distal to the lowest divided ring; this acts as a tracheal stent for 5–10 days.

Patients are cared for in the PICU, where meticulous attention to the tracheal tube is needed. Tracheal tube blockage or accidental extubation are very hazardous as attempts at reintubation can result in the bevel of the tracheal tube being pushed through the anterior tracheal wall to create a false passage. If extubation occurs, nasotracheal reintubation should not be attempted in the PICU as the angle of tracheal tube passing through the larynx from the nose encourages anterior perforation through the surgical division. The airway should be supported with a face mask to achieve oxygenation and orotracheal intubation attempted. Afterwards the patient can be returned to theatre for nasotracheal intubation in controlled circumstances. At 5–10 days, extubation is attempted whilst using steroid cover.

Laryngotracheal Reconstruction

This may be performed as a single-stage or two-stage procedure with a tracheostomy. It involves a similar approach to the cricoid split but opens the larynx anteriorly and posteriorly if required. Harvested rib cartilage is interposed into the anterior and posterior split, thereby increasing the diameter of the airway. If performed as a single-stage procedure, with no covering tracheostomy, the anaesthetic and PICU considerations are the same as those for the cricoid split, including the caveat regarding reintubation. If a posterior graft is needed, a sterile cuffed flexometallic tracheal tube or cut-down RAE tube is placed by the surgeon in the trachea distal to the graft site; ventilation is continued in this manner until just before the anterior graft is ready to be placed. At this point, a larger nasotracheal tube is passed with the tip positioned just below the graft site by the surgeon under direct vision. Wet neurosurgical patties can be used to pack around this tube to create a temporary seal for intermittent positive pressure ventilation (IPPV). The patient is returned to the PICU for care, as described earlier. Patients tolerate nasotracheal tubes well, and after the first 24–48 hours only minimal sedation is needed.

Laryngotracheal reconstruction is also performed as a two-stage procedure, the first stage being a tracheostomy. At the second stage, anaesthesia is induced through the pre-existing tracheostomy; maintenance is with an opioid, muscle relaxant and volatile agent. Intravenous fluids are given and continued postoperatively, and a nasogastric tube is passed. To manage the airway, a cuffed flexometallic tracheal tube or cut-down RAE tracheal tube is inserted through the tracheostome, after which the anaesthetist should check for equal ventilation. The tube is secured by surgical suture just below the tracheostome. Care is needed during the operation as surgical manipulation can move the tube, resulting in extubation or bronchial intubation; the cuff can also be

pierced by surgical suturing. Should this happen, the surgeon will need to assist with tube positioning. Wet neurosurgical patties will create a temporary seal if the cuff ruptures.

A stent is placed in the trachea to support the grafts, after which the anterior larynx is closed. The flexometallic tube is removed after careful tracheal suctioning, a tracheostomy tube is reinserted, and the patient is awoken to be returned to the ENT ward. Humidified oxygen is given via a tracheostomy mask. A CXR is required to exclude a pneumothorax, which may occur following rib harvest. Analgesia is with paracetamol, an NSAID and morphine patient- or nurse-controlled analgesia (PCA/NCA). A local anaesthetic infusion through an epidural catheter placed in the site of rib harvest can afford useful pain relief for up to 72 hours.

Cricotracheal Resection

Short segment tracheal resection can be performed for Grade III and IV SGS. The patient will already have a tracheostomy, and the approach to anaesthesia is the same as the two-stage laryngotracheal reconstruction. A segment of trachea is excised, and a new cricotracheal anastomosis is made. Difficulties with the temporary cuffed flexometallic tube are even more likely in this operation. More complex slide tracheoplasties are used for patients with long-segment tracheal stenosis; these require cardiopulmonary bypass and are highly specialised operations.

Non-airway ENT Surgery

Middle Ear Surgery

Exploration of the middle ear requires the anaesthetist to consider:

- Control of bleeding
- Preservation of the facial nerve
- Avoidance of graft displacement

Procedures include:

- Mastoidectomy
- Myringoplasty
- Cochlea implantation

Minimising Blood Loss

Bleeding can be of arterial origin secondary to a hyperdynamic circulation with a high cardiac output, hypertension and tachycardia. Control of heart rate and cardiac output will minimise this loss. Venous ooze secondary to raised internal jugular venous pressure may be caused by poor patient positioning, partial airway obstruction during spontaneous respiration, abdominal compression or raised mean intrathoracic pressure with IPPV or PEEP.

Strategies to minimise blood loss during middle ear surgery are presented in Table 21.2. These involve controlled hypotension which may be defined as a reduction of systolic blood pressure to 80 to 90 mmHg, a reduction of mean arterial pressure (MAP) to 50–65 mmHg or a 30% reduction of baseline MAP. Total intravenous anaesthesia has revolutionised anaesthesia for middle ear surgery. The blood pressure cuff should be sited on the arm opposite to the operation to avoid interference with readings by surgical activity. The remifentanil infusion is stopped 15 minutes before the end of surgery, and a long-acting opioid, paracetamol and NSAID are given. A postoperative antiemetic should be prescribed, as PONV can be problematic after middle ear surgery.

Preservation of the Facial Nerve

The tympanic segment of the facial nerve is at risk during middle ear surgery; facial nerve monitoring is used, based upon electromyography, and requires neuromuscular function. Neuromuscular blockers are thus avoided.

Avoiding Graft Displacement

Nitrous oxide (N_2O), being more soluble than nitrogen, diffuses in and out of body cavities more quickly than nitrogen. When the middle ear has been closed by a myringoplasty, termination of N_2O will result in a negative pressure being applied to the graft. Using TIVA or avoiding N_2O is ideal.

Surgery for Congenital Ear Defects

Children with congenital defects of the external ear present for the insertion of osseointegrated temporal screws for an artificial pinna or bone-anchored hearing aid; reconstructive surgery to form an external ear is also undertaken (see Chapter 28). Many of these defects are associated with Treacher Collins and Goldenhar syndromes, both of which present difficulty for tracheal

Table 21.2 Strategies to minimise blood loss during middle ear surgery

Strategy	Method	Comment
Smooth induction of anaesthesia avoiding tachycardia or hypertension	Calm, relaxed patient	Sedative premedication if required Avoid anticholinergic medication
Avoid coughing or straining on intubation	Establish TIVA before intubation	Use remifentanil to facilitate intubation, 0.5–1 mcg kg^{-1} over 1 min: Propofol loading dose Use topical laryngeal anaesthesia 1 mg kg^{-1}
Keep the venous pressure low	Patient's head up tilted to 15–20° positioning	Avoid excessive head turning as it may obstruct the contralateral internal jugular vein
Ventilation strategy	Aim for normocapnia	Slow respiratory rate No PEEP Long expiratory time
Aim for a systolic blood pressure of 80 mmHg	Analgesia: infiltration with lidocaine and adrenaline1:200,000 Anaesthesia (TIVA): remifentanil 0.1–0.5 mcg kg^{-1} min^{-1} Propofol 2% Manual control or target control. Propofol manual control: 13/11/9 mg kg^{-1} h^{-1} Reduce at 10 min intervals until 9 mg kg^{-1} h^{-1} maintenance	Titrate to desired blood pressure

intubation. Anaesthesia for these operations can usually be managed using a flexible LMA, which obviates the need for intubation. It is essential to be satisfied with the performance of the LMA with the head in the operative position before surgery commences.

Head and Neck Tumours

Extensive dissection may be required in some head and neck masses. Anaesthesia management includes potentially difficult intubation, appropriate monitoring, compensation for heat loss and preparation for rapid transfusion if needed, as in any major surgical intervention.

Juvenile Nasopharyngeal Angiofibroma

Juvenile nasopharyngeal angiofibroma (JNA) is a highly vascularised and histologically benign tumour of the nasal cavity and paranasal sinuses, with aggressive behaviour and locally invasive growth patterns. It comprises 0.05% of head and neck tumours and predominantly occurs in young boys, with a mean age of presentation of 15 years. The best treatment to date remains surgical removal of the tumour. Preoperative embolisation is used for virtually all cases of JNA, resulting in reduction of intraoperative bleeding; occlusion of surgically inaccessible arterial feeding vessels; decreased operative time; and improved surgical visualisation, identification and protection of adjacent structures. This results in a significant reduction of overall surgical complications and is the standard of care in most centres. The anaesthetist must be prepared for significant blood loss. Large bore cannulae, tranexamic acid, cross-matched blood available and remifentanil infusion are advised.

Ex-Utero Intrapartum Treatment

The ex-utero intrapartum treatment (EXIT) procedure is performed by a multidisciplinary team during caesarean section. It is indicated when the neonate's airway is at significant risk of severe obstruction immediately after birth. The technique allows the fetus to be partially delivered and the airway to be controlled whilst placental perfusion is maintained. It was originally used in 1989 to

deliver a fetus with a large anterior neck mass. It then became part of the antenatal treatment of congenital diaphragmatic hernias. In this condition, it was discovered that prenatal obstruction of the trachea using surgical clips could allow expansion and maturation of fetal lungs. The EXIT procedure allowed removal of the tracheal clips prior to delivery whilst the fetus remained well oxygenated on placental bypass.

The EXIT procedure is now indicated for other fetal conditions where airway obstruction is a significant risk immediately after birth. These conditions include giant fetal neck masses, lung or mediastinal tumours, congenital high airway obstruction syndrome (CHAOS) and EXIT to extracorporeal membrane oxygenation (ECMO) for certain congenital cardiac conditions and congenital cystic adenomatoid malformation. Recently, EXIT-to-airway for severe micrognathia has been added to this list. An EXIT procedure provides the opportunity to maintain oxygenation for up to 60 minutes prior to placental separation. This window of opportunity can be used to safely intubate the airway prior to delivery.

Key Points

- Extreme vigilance is essential during procedures on the airway.
- Diagnostic microlaryngoscopy and bronchoscopy requires spontaneous ventilation to be maintained. This necessitates good topical anaesthesia of the larynx.
- Postoperative vomiting occurs commonly during ENT surgery, and antiemetics should be administered in all cases.
- TIVA is the most appropriate mode of anaesthesia for middle ear surgery.

Further Reading

Cook TM, Wolf AR, Henderson AJ. Changes in blood-gas tensions during apnoeic oxygenation in paediatric patients. *British Journal of Anaesthesia* 1998 September; 81(3):338–42. doi: 10.1093/bja/81.3.338.

Dick JR, Wimalasundera R, Nandi R. Maternal and fetal anaesthesia for fetal surgery. *Anaesthesia* 2021 April; 76(Suppl 4):63–8.

Din T, Abdalla T, Chiesa-Estomba C et al. YO-IFOS guidelines for pediatric ENT surgery during COVID-19: an overview of recommendations. *Laryngoscope* 2021 August; 131 (8):1876–83. doi: 10.1002/lary.29335. Epub 2020 Dec 25. PMID: 33325043 Review.

Hardman JG, Wills JS. The development of hypoxaemia during apnoea in children: a computational modelling investigation. *British Journal of Anaesthesia* 2006 October; 97 (4):564–70.

Mitchell RB, Archer SM, Ishman SL et al. Clinical practice guideline: tonsillectomy in children (update). Executive summary. *Otolaryngology – Head and Neck Surgery* 2019 February; 160 (2):187–205. doi: 10.1177/0194599818807917.

Zubair A, Sutton L, Murkin C et al. The changing face of paediatric airway endoscopic surgery: an 8-year single surgeon review. *International Journal of Pediatric Otorhinolaryngology* 2022 May; 156:111104. doi: 10.1016/j.ijporl.2022.111104. Epub 2022 Mar 15.