Anaesthesia 2018, 73, 1400–1417 doi:10.1111/anae.14307

Guidelines

Multidisciplinary guidelines for the management of paediatric tracheostomy emergencies

C. Doherty,[1] R. Neal,[2] C. English,[3] J. Cooke,[4] D. Atkinson,[5] L. Bates,[6] J. Moore,[5] S. Monks,[7] M. Bowler,[8] I. A. Bruce,[9,10,13,14] N. Bateman,[10] M. Wyatt,[11] J. Russell,[12] R. Perkins[1] and B. A. McGrath[5,14] on behalf of the Paediatric Working Party of the National Tracheostomy Safety Project

1 Consultant, 8, Specialty Trainee, Department of Paediatric Anaesthesia, 3 Tracheostomy Specialist Nurse, Department of Paediatric ENT, 9 Professor, 10 Consultant, Department of Paediatric Otolaryngology, Royal Manchester Children's Hospital, 5 Consultant, Department of Anaesthesia and Intensive Care Medicine, Manchester University NHS Foundation Trust, Manchester, UK
2 Consultant, Paediatric Intensive Care Medicine, Paediatrics, Birmingham Children's Hospital, Birmingham, UK
4 Tracheostomy Specialist Nurse, 11 Consultant, Department of Paediatric Otolaryngology, Great Ormond Street Hospital, London, UK
6 Consultant, Department of Anaesthesia and Intensive Care Medicine, Royal Bolton Hospital, Bolton, UK
7 Consultant, Department of Anaesthesia, East Lancashire Hospitals NHS Trust, Burnley, UK
12 Consultant, Department of Paediatric ENT, Our Lady's Children's Hospital, Dublin, Ireland
13 Manchester Academic Health Science Centre, Manchester, UK
14 Division of Infection, Immunity and Respiratory Medicine, Faculty of Biology, Medicine and Health, University of Manchester, Manchester, UK

Summary

Temporary and permanent tracheostomies are required in children to manage actual or anticipated long-term ventilatory support, to aid secretion management or to manage fixed upper airway obstruction. Tracheostomies may be required from the first few moments of life, with the majority performed in children < 4 years of age. Although similarities with adult tracheostomies are apparent, there are key differences when managing the routine and emergency care of children with tracheostomies. The National Tracheostomy Safety Project identified the need for structured guidelines to aid multidisciplinary clinical decision making during paediatric tracheostomy emergencies. These guidelines describe the development of a bespoke emergency management algorithm and supporting resources. Our aim is to reduce the frequency, nature and severity of paediatric tracheostomy emergencies through preparation and education of staff, parents, carers and patients.

Correspondence to: C. Doherty
Email: catherine.doherty@mft.nhs.uk
Accepted: 14 March 2018
Keywords: airway; guideline; paediatric; tracheostomy
This article is accompanied by an editorial by MacKinnon and Volk, Anaesthesia 2018; 73: 1309–1312.

Recommendations

1. Bedhead signs communicate essential airway details and should be mandated as part of the theatre sign--out process following tracheostomy surgery
2. The best available assistance should be summoned early to an emergency and institutions should plan for this in advance
3. Essential airway equipment must be immediately available and accompany the patient
4. High- and low-fidelity simulation has an important role to play for healthcare staff, families and carers, using the algorithm as a checklist to guide responders
5. Healthcare professionals who look after children with tracheostomies should receive regular training in routine and emergency tracheostomy management

Introduction

The indications for tracheostomy in children have evolved over the years, which have influenced the incidence of paediatric tracheostomy in our hospitals and communities and the baseline characteristics and comorbidities of these children. Vaccination programs and improvements in anaesthetic skills and equipment have significantly reduced the need for emergency tracheostomy due to airway obstruction, especially as a consequence of upper airway infection [1]. The commonest indications for tracheostomy in a child include: actual or anticipated long-term ventilatory support; requirement for broncho-pulmonary secretion management; or the presence of a fixed upper airway obstruction, typically subglottic stenosis, bilateral vocal cord paralysis, tumours and congenital airway malformations and associated syndromes [2–6]. Respiratory papillomatosis, caustic alkali ingestion and craniofacial syndromes have increased the frequency of paediatric tracheostomy over the past decade, although evolving surgical techniques such as microdebridement may avoid tracheostomy in some circumstances.

Tracheostomies may be required from the very first days of life, including peri-delivery exit procedures for known fetal airway abnormalities [7]. Approximately 1200 surgical tracheostomies were performed in children aged 16 years or less during 2014–2015 in England [8]. One-third of the procedures were performed in children under the age of one year and two-thirds in children under the age of four years, a consistent finding since the 1970s [9, 10]. An estimate from the USA in 1997 suggested nearly 5000 paediatric tracheostomies were performed [11]. Most case series report a higher incidence of male children requiring tracheostomy, probably because they are more susceptible to genetic diseases [12]. Tracheostomies may be temporary, although they remain in situ significantly longer than temporary tracheostomies in adult practice, especially if the child has a degree of neurological impairment [13]. Similarly, tracheostomies are much more likely to be required permanently in children, with significant lifestyle changes for the child and their parents or carers [14–16]. Children with reversible, treatable or acquired pathologies, such as vocal cord palsies or subglottic stenoses, are more likely to get decannulated and the number of associated comorbidities is linked to the likelihood of eventual decannulation [17]. Treatment can take months to years, sometimes waiting for children to grow or to undergo staged maxillofacial or head and neck reconstructive or corrective surgery.

Performing a tracheostomy and changing a tracheostomy tube can be difficult in paediatric patients, due to anatomical and technical factors. The trachea is small and pliable and can be difficult to palpate, with the technical challenges magnified by the short neck, head and neck vessels and the pleura extending into the neck. The size of the trachea dictates that a cartilage window should not be used in children, to avoid creating a stenotic segment at the site of the tracheostomy. Instead, a vertical tracheotomy is used, which may hinder replacement of blocked, or dislodged, tube until stoma maturation is complete. 'Maturation sutures' are used to accelerate this process, and 'stay sutures' are sited on either side of the vertical tracheostomy to aid opening of the lumen in an emergency, before the planned first tube change [18].

Tracheostomies in children are typically open surgical procedures, although percutaneous and hybrid techniques have been described [19, 20]. In contrast, adult tracheostomies are predominantly performed percutaneously with the commonest indication being to aid weaning from mechanical ventilation in the acutely critically ill [21]. Tracheostomy for children is usually a planned procedure, often following relatively long stays on the intensive care unit when compared with adult practice [22].

Due to the small tracheal diameter, paediatric tracheostomy tubes are generally uncuffed and do not have an inner tube, to avoid reducing the internal diameter of the tracheostomy tube lumen further [4]. Neonatal tracheostomy tubes are shorter in length than the paediatric tubes. Cuffed tubes are occasionally required if high ventilation pressures are needed or if there is a high risk of aspiration [23].

Around 20% of adults who undergo tracheostomy in the UK and USA do not survive to hospital

discharge [24–27]. Comparable figures for paediatric patients undergoing tracheostomy come from smaller case series, but are typically reported at between 2% and 10% with significant geographical variation [3, 9, 28–34]. In both age groups, mortality is largely due to the significant underlying comorbidities that contribute to the requirement for tracheostomy [35]. However, morbidity and mortality that is directly due to the tracheostomy itself does occur in the peri-operative, hospital and community settings, contributing to a significant healthcare resource burden [36].

Tracheostomy complications occur surprisingly frequently and influence outcomes [37, 38]. One recent North American paediatric tertiary centre study reported early complications in 11% and late complications in 68.8% of all tracheostomies inserted [39], which is consistent with other reported institutional case series [2, 30, 32, 33, 38, 40–43]. The early postoperative complication rate in preterm infants may be double that of full-term infants [44], and the requirement for tracheostomy in the preterm period is also associated with poor developmental outcomes [45]. The commonest reported incidents describe tube displacement, blockage or a tube being pulled out [46]. Children who are ventilator dependant have worse outcomes following an incident than those breathing unaided [47]. Complications such as subglottic stenoses or granuloma formation assume greater importance in the child due to the small calibre of the airway, although accidental decannulation may also become more prevalent as manual dexterity develops in older children. The vast majority of significant events occur more than one week after the tracheostomy insertion, including catastrophic events occurring at home [28].

Medicolegal reports reinforce the potential for severe and permanent damage when tracheostomy complications occur, most commonly for peri-operative negligence, dislodged tubes and mucous plugs. Award amounts were high at a median of USD $2,000,000 in one US study with otolaryngologists and nurses the most commonly named defendants [48]. This demonstrates the importance of proper training of all members of a multidisciplinary team, which is often found lacking [49].

Complications and incidents relating to tracheostomies and laryngectomies in adults have been well documented in a series of national reports and analyses of data registries [24, 26, 50–52]. When incidents occur, some measureable harm is reported in 57 to 82%, with the level of harm dependant on location [50, 51, 53, 54]. Recurrent themes that emerged from incident analyses have led to common recommendations to improve care, including the following:

- Training for tracheostomy emergencies including recognition and management of blocked and displaced tubes
- Hospital-wide protocols and standardised training in tracheostomy care
- Bed-side information including details of the airway and tracheostomy tube
- Bed-side tracheostomy boxes containing essential equipment for each patient

Understanding the potential problems with tracheostomy care led to the development of nationally recognised guidelines for the management of adult tracheostomy and laryngectomy emergencies, led by clinicians at the National Tracheostomy Safety Project (NTSP) [55]. Emergency guidelines were supported by multidisciplinary stakeholder Royal Colleges and professional and patient groups and a comprehensive package of educational resources (www.tracheostomy.org.uk). Implementation of these guidelines has had an impact on the quality and safety of care [53]. These guidelines are, however, not immediately applicable to children.

Although there are clear differences between adult and paediatric tracheostomy care and practice, the recurrent themes we have identified are likely similar at an institutional and organisational level [56]. Many of these adverse events are avoidable [57], and are also amenable to prospective quality improvement strategies [58]. Therefore, the Paediatric Working Group of the NTSP was established with the aim of developing paediatric tracheostomy emergency guidelines, using a similar methodology to the previously published NTSP adult tracheostomy emergency guidelines [55].

Our objective was to develop simple, clear and authoritative guidelines that were specific for children with tracheostomies, following wide consultation with key national stakeholders and bodies involved in paediatric tracheostomy care. Our focus was management of post-placement incidents and the immediate management of potentially life-threatening complications. As with the adult guidelines, we aimed to produce resources that were applicable to all multidisciplinary staff, regardless of background, that could be taught consistently and easily as part of standard education packages. These guidelines were also to be applicable for carers and parents. Children with a tracheostomy often have other comorbidities that require care at different healthcare sites and hence

the importance of having a standardised guideline for all to use. The purpose of this article is to present these paediatric guidelines and their rationale.

Methods

A Paediatric NTSP National Working Party was formed in 2013 comprising a multidisciplinary team of paediatric ear, nose and throat (ENT) surgeons, paediatric intensive care unit (PICU) consultants, paediatric anaesthetists and specialist paediatric tracheostomy care nurses (both hospital and community based) from paediatric hospitals across the UK and Ireland.

A literature review was undertaken in November 2015 and updated in February 2017, which searched databases (Embase, PubMed, Medline), search engines (Google and Google Scholar) and NHS Evidence bases (www.evidence.nhs.uk). Scientific papers and existing national or institutional guidelines with English language abstracts were retrieved and reviewed, along with any resources known to the Working Party members. Appropriate consideration was given to 'UK' and 'US' spellings of key words. Two authors (BM and CD) filtered publications, resources, websites, expert opinion and communications, with further articles retrieved from relevant references. The majority of published literature regarding paediatric tracheostomies consists of single-centre retrospective reviews of practice, detailing indications and surgical techniques, with few reporting emergency management procedures [59, 60].

Identified consensus statements and best-practice guidelines suggested that healthcare professionals who look after children with tracheostomies should receive regular training in routine and emergency airway management [61–63]. One national survey of US otolaryngologists reported that 98% of respondents were instructing families and carers of tracheostomised children in the recognition of respiratory distress, emergency management and tube replacement [64]. However, comprehensive, universal guidance was not described in the published literature. We also reviewed local guidelines and policies for the management of paediatric tracheostomy emergencies that were known to the authors or retrieved through our search strategies. Most detailed tracheostomy care bundles and daily care, with little reference to emergency management.

This guideline recognises the lack of a consensus for managing a paediatric tracheostomy emergency or paediatric front-of-neck airway (FONA) and the limited evidence for any chosen technique. We make recommendations to guide the multidisciplinary responder, carer or team in managing the commonest tracheostomy problems that occur in children, using simple and familiar techniques that are likely to be of benefit, before implementing more advanced or invasive interventions. As with other difficult airway management guidelines, regardless of the chosen techniques, prior familiarity and preparedness will maximise the chances of success [65, 66].

The Paediatric Working Group had developed an initial draft guideline in 2013 comprising emergency algorithm and paired bedhead sign. The design of the algorithm was based on the published guidelines for management of adult tracheostomy and laryngectomy emergencies [55], with modifications where there were felt to be significant differences in paediatric management. Early versions were discussed among the Working Party and our multidisciplinary colleagues, and were tested using high-fidelity medical simulation at local bespoke meetings using faculty and volunteers. Key steps were designed to address contributing factors to poorly managed emergencies, which include lack of access to information or emergency algorithms, loss of situational awareness and poor communication [50, 51]. We recognised the role that simulation could play in further refining the algorithm key steps and have previously described testing versions of the algorithm in over 450 volunteer healthcare professional encounters at national and international meetings, where the algorithm was also formally presented [59]. We were able to demonstrate significant improvements in performance metrics when multidisciplinary responders followed the algorithm in similar scenarios. Scenarios were completed more quickly, the simulated children were less hypoxic and more candidates called for help [59].

The near final version of the algorithm was agreed by the Working Party and made freely available on the NTSP website (www.tracheostomy.org) in May 2015. The algorithm pages were accessed 99,096 times up to the end of January 2017, with the paediatric algorithm viewed 4,250 times. Email comments were invited but none were received. During this period, the algorithm was also assessed in six tracheostomy emergency courses hosted by the Advanced Life Support Group (www.alsg.org) with detailed feedback from instructors and participants.

The Working Party invited formal reviews of the algorithm from several organisations with a stated interest in patient safety, airway management and professional guidelines in children. These included the Advanced Life Support Group, the Association of Paediatric Anaesthetists, the British Association of Paediatric Otolaryngologists, the Global Tracheostomy Collaborative, the

Paediatric Intensive Care Society, the Resuscitation Council (UK) and the Royal College of Paediatrics and Child Health.

The Working Party agreed the final versions of the algorithm and paired bedhead signs in January 2017 after reviewing feedback. The project has not been directly funded, although the NTSP has supported some meeting costs.

Results

Paediatric patients who require a tracheostomy are more likely than adults to have a difficult or impossible to manage native upper airway, and airway management is made more difficult by intercurrent critical illness and dependence on invasive ventilatory support [67, 68]. As with the adult guidelines, several basic principles underpin the paediatric guidance.

First, bedhead signs were adapted to provide essential initial information to emergency responders that was specific to the child and to their particular tracheostomy, consistent with the views of the Intensive Care Society, Difficult Airway Society, National Patient Safety Agency and the adult NTSP work [52, 55, 69–71]. A wide range of tracheostomy tubes and associated devices are available, including some custom-made devices [72, 73]. Each has specific features, which are important in an emergency when suction or a tube change may be urgently required, and regular carers, parents or the medical records are not immediately available. As different manufacturers' tubes come in subtly different sizes and lengths, bedhead information such as the internal diameter of the tracheostomy tube, the calibre of suction catheters to be used, and the depth that a suction catheter should inserted to should be kept with the child at all times [72].

The bedhead signs also incorporate details of the child's upper airway patency, and ease of management. We recommend that multidisciplinary teams complete these fields based on historical airway management (from anaesthetic charts or operation notes) or following airway management procedures (often in theatre). It may be clear that it is much easier to replace a tube into the tracheostomy stoma or the native upper airway(s) should tracheostomy blockage or displacement occur and this information must be clearly communicated. We recommend that completion of the bedhead sign be mandated as part of the theatre sign out procedure following a new tracheostomy procedure, or airway management in theatre.

There are two versions of this bedhead sign; the 'NEW tracheostomy' sign (Fig. 1a) is used up to first tube change and the 'Tracheostomy' sign is used thereafter (Fig. 1b). New stomas are likely to have the additional safety features of 'stay sutures' (Figs. 2a and b) and 'maturation sutures' (Fig. 3) which secure the edge of the tracheal wall to the anterior neck skin [39, 63]. The location and purpose of these sutures are documented on the bedhead sign and the stay sutures are typically removed at the first tube change. This often coincides with discharge from a critical care environment to ward level care. The (established) tracheostomy bedhead sign is then completed.

Although much less common in children than an open surgical procedure, if the tracheostomy has been percutaneously inserted, this should be clearly recorded on the bedhead sign [19]. It is likely that the dilated tissues of a percutaneously formed stoma will recoil in the event of tube displacement, making re-insertion potentially more difficult, especially in the first 7–10 days following insertion [74]. This knowledge may direct responders to manage the upper airway as a priority. A surgically-formed stoma can reasonably be expected to be matured enough to allow safe tube exchange after three days, dependant on patient factors or local practices [63].

The paired paediatric bedhead signs are provided on the NTSP website in Microsoft PowerPoint format to allow for local adaptations, and double-sided versions ensure that the emergency management algorithm is also immediately available.

The second principle that the Working Party adopted from the adult guidelines was that the algorithm and bedhead should be able to be used by multidisciplinary staff who might care for a child in the community, secondary or tertiary locations. Information should also be understandable by parents and carers and the algorithm should be able to guide non-medically trained primary responders in the initial management of tracheostomy emergencies. These primary responders may not only include parents, carers and community or school nurses but also hospital staff with limited training and infrequent contact with tracheostomy patients [75]. Such responders will be managing children with established stomas and are guided in basic responses to tracheostomy emergencies. Responders with more advanced airway and tracheostomy skills will manage children with new tracheostomies and provide secondary support to the management of established tracheostomy problems. The algorithm also guides secondary responders through basic management but continues to primary and secondary oxygenation techniques. Two double-sided paired bedhead signs and algorithms are therefore provided:

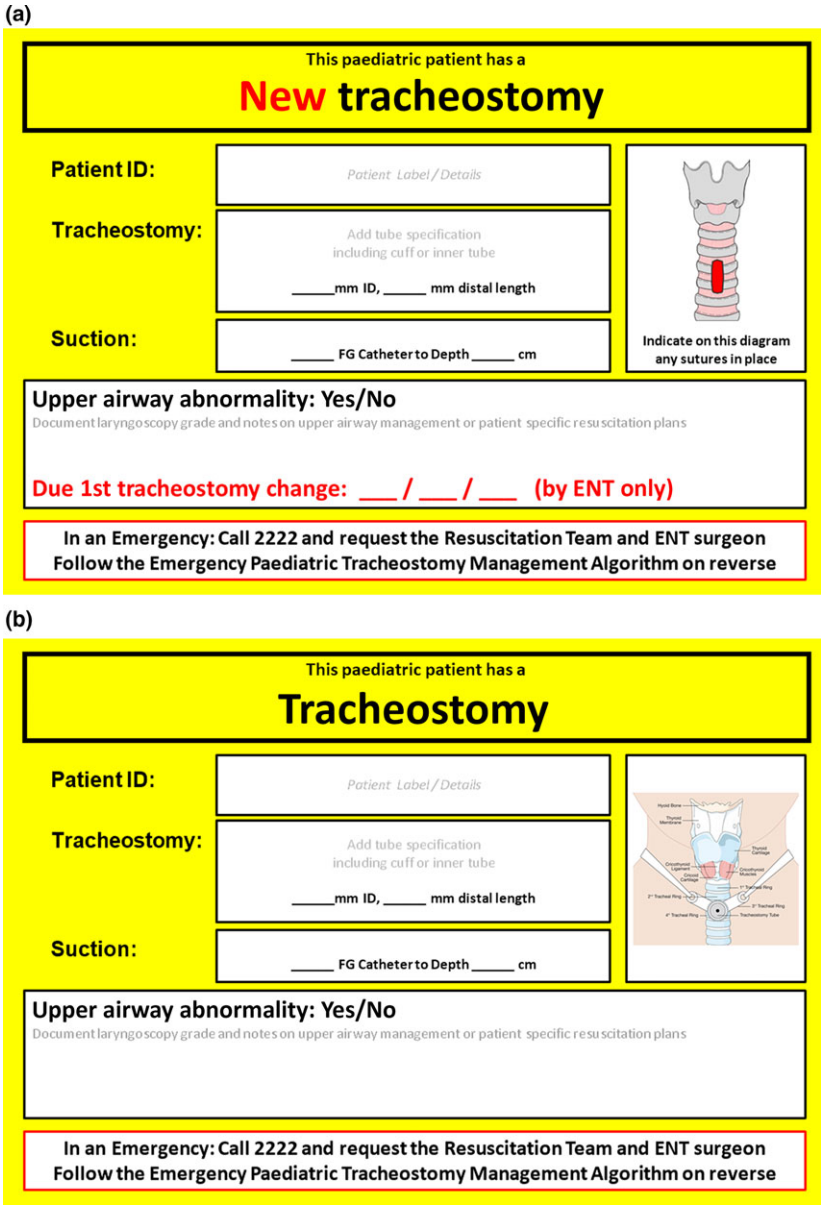

Figure 1 (a) The "NEW tracheostomy" bedhead sign is used up to first tube change (a) and the "Tracheostomy" sign is used thereafter (b).

1 Front: **NEW tracheostomy** bedhead sign
2 Reverse: basic and advanced (full) responder algorithm
3 Front: **Tracheostomy** bedhead and combined primary responder algorithm
4 Reverse: basic and advanced (full) responder algorithm (Fig. 4).

This paired information should become the 'tracheostomy passport' for the patient upon hospital discharge and should be kept with or inside the dedicated emergency tracheostomy box to aid staff if the child presented to an unfamiliar care setting (Fig. S1).

The overall style of the algorithms was based on the successful flow charts produced by the Difficult Airway Society and the NTSP [55, 66, 76]. The principle of oxygenation of the patient remained a priority. This does not necessarily mean securing the airway by (re)insertion of an airway device immediately, as less invasive methods of oxygenation may be adequate and safer for responders to undertake, depending on equipment, environment and training [55, 76]. The second principle that was

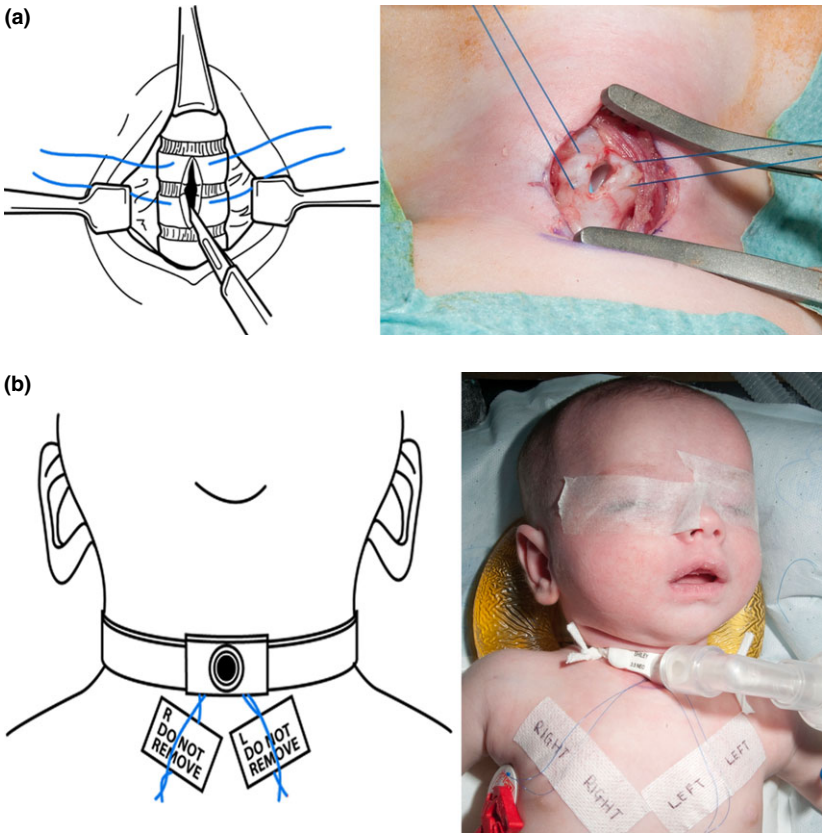

Figure 2 (a) Stay sutures pass through thrachea and can be secured on the chest of the patient. Pulling these sutures will elevate the trachea and widen the stoma. (b) Stay sutures in situ following insertion of surgical tracheostomy.

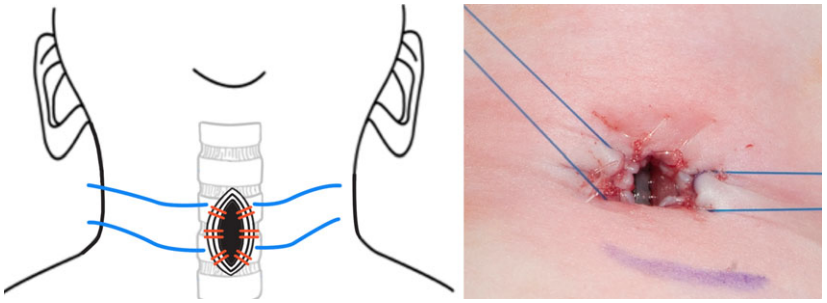

Figure 3 Maturation sutures (red) secure the tracheal stoma to the skin. These are different to the stay sutures (blue) shown in the photograph below.

retained was that the best assistance should be summoned as early as possible. Ideally, assistance should include other members of the multidisciplinary team who are trained and competent to manage tracheostomy emergencies, working in adequately staffed and equipped environments [77]. We recommend that details of who to call in an emergency should be clearly displayed on the bedhead sign and this should be agreed on admission to the clinical area or upon insertion of a new tracheostomy.

The following section includes detailed discussion and explanation of the algorithm. This guidance is applicable to any urgent or emergency situation that develops in a child from birth to adolescence who has an existing tracheostomy. Adverse clinical signs may (or may not) be apparent before an emergency occurs. Such signs have been referred to as 'Tracheostomy Red Flags' and should be familiar to staff caring for patients with tracheostomies [78]. Red flags are summarised in Table 1. Red flags may or may not be related to airway compromise. As with

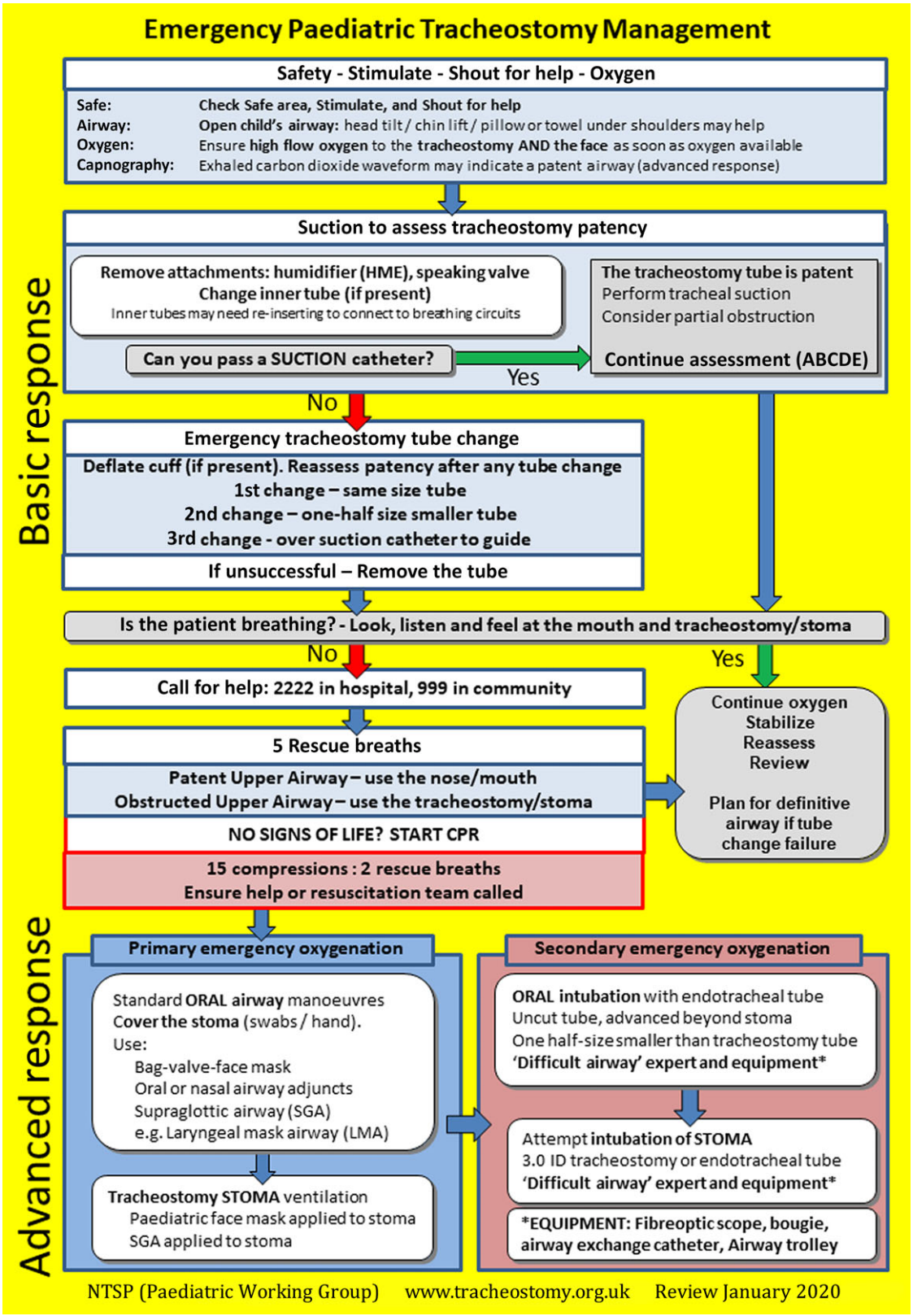

Figure 4 National tracheostomy safety project emergency paediatric tracheostomy emergency management algorithm.

Table 1 Paediatric tracheostomy red flags.

Airway red flags	Breathing red flags
• Child with a minimal leak previously – suddenly able to talk/audible air leaks/bubbles seen at mouth • Suction catheter not passing through tracheostomy • Grunting, snoring or stridor	• Not breathing (or apnoea) • Increasing ventilator support • Increasing oxygen requirements • Respiratory distress — Accessory muscle use — Increased respiratory rate — Higher airway pressures — Lower tidal volumes • Noisy breathing
Tracheostomy-specific red flags	**General red flags**
• Has a visibly displaced tracheostomy tube • Has blood or blood-stained secretions around the tube – a recently performed or changed tracheostomy bleeds a little, but if in doubt, you should get it assessed • Reports increased discomfort or pain	Any physiological changes can be due to an airway problem. Specifically, changes in: • Respiratory rate • Heart rate • Blood pressure • Level of consciousness • Anxiety, restlessness, agitation and confusion may also be due to an airway problem.

established management of the critically ill child, assessment of the airway occurs first [79, 80].

The clinical situation may make it clear that deviation from the order of the guided responses in the algorithm is necessary. For example, if the initial assessment demonstrates that a tracheostomy tube is visibly completely displaced, then the responders should proceed to emergency tube change and re-insertion. Similarly, if the patient is bleeding from the tracheostomy or stoma site, the algorithm will guide assessment of the airway with steps most likely to restore or maintain patency. However, responders must address any other acute clinical concerns such as haemorrhage control and cardiovascular resuscitation in parallel.

Initial assessment

The first steps of the algorithm concern approaching safely, gentle stimulation of the child and shouting for help: 'Safety, Stimulate, Shout for help'. The algorithm guides responders to assess the patency of the native airway and tracheostomy using clinical assessment and suction initially. Trained clinical staff or competent carers should be capable of performing these assessments and interventions. If the responder is not competent or confident, then it is appropriate to call for further help at this point ('2222' hospital resuscitation team or '999' for a paramedic outside of the hospital environment).

Responders should next open the child's native upper airway and then assess for spontaneous breathing at the upper airway and tracheostomy. Depending on the age of the child, different positioning may be required to open the upper airway, although a chin lift ('sniffing the morning air') with or without jaw thrust is likely to be useful in children of all ages [80]. A more neutral position may be useful in children under two years of age and a pillow or rolled towel under the child's shoulders may improve airway patency and access to the tracheostomy [60, 78, 79]. The lateral position may be of benefit in some children, especially if there is known upper airway obstruction, although this position may limit access to the anterior neck [81].

Patency of the airway should be evaluated by looking, listening and feeling for airflow at the mouth/nose and the tracheostomy (Fig. S2), supplemented by waveform capnography where possible. Assessment may be aided using a Mapleson F anaesthetic breathing circuit if available and if staff are competent to use this equipment, as the movement of the bag can be helpful in indicating gas movement via the airways, especially the tracheostomy. Such a circuit can be attached directly to the tracheostomy tube or applied over an open stoma if the tracheostomy tube has been displaced. However, care must be taken as attempting to ventilate through a displaced tracheostomy can cause subcutaneous emphysema and further complicate airway management [82, 83].

Additional clinical signs of respiratory distress or airway obstruction should be sought while assessing the airway. The most useful clinical signs are likely to be stridor, accessory muscle use, tracheal tug, sternal, subcostal and intercostal recession, although an agitated, restless or obviously distressed child may also have a degree of airway obstruction and signs may become absent as obstruction worsens [84].

High-flow oxygen should be delivered to the patient's face and to the tracheostomy if available. Note that as two oxygen sources are required for this, both wall oxygen and a second supply (e.g. the resuscitation trolley) will be needed. Ideally, all tracheostomy patients should be nursed at a bed with two oxygen pipeline

supplies. If only one oxygen supply is available, then this should be applied to the airway from which spontaneous breathing can be detected from (if the child is breathing); the face or tracheostomy.

The competent use of waveform capnography has been consistently identified as one of the key interventions to improve the safety of airway management [52, 85–87]. We recommend that waveform capnography should be immediately available in paediatric critical care areas and available to be brought rapidly to the bed-side of a child with a tracheostomy emergency anywhere within a hospital. We recognise that oxygen and capnography may not be available outside of the hospital environment.

If the child is breathing spontaneously and gas flow is detected via the tracheostomy tube, then the tube is at least partially patent. If there are signs of respiratory distress then proceed through the algorithm, otherwise consider other causes for the deterioration that are not related to the child's tracheostomy. The ABCDE approach advocated by the Advanced Paediatric Life Support guidelines is recommended [79].

Help and equipment

If the initial assessment demonstrates signs of respiratory distress, further help should be summoned. Who is called will depend on the patient, the responder, the location and the time of day. Local arrangements for emergency responders must be agreed as part of departmental and hospital-wide policy and include contact methods for clinical staff with advanced airway skills (often anaesthetists), ENT surgeons and/or specialist nursing staff. The bedhead sign will detail who should be called and how. Responders can vary from hospital to hospital and depend on the time of day, but will often include resuscitation teams, plus specialists from ENT, anaesthesia, paediatrics and paediatric intensive care.

Responders should ensure that emergency equipment is brought to the patient. Paediatric trachi-cases contain standardised emergency equipment for each patient, are portable, and should be with the child at all times (Fig. S1) [78]. Trachi-cases should also contain a copy of the bedhead information and algorithm. Tracheal dilators are not included in the emergency equipment as there is potential to cause trauma in the smaller airway, further compromising airway management [72]. Specialist equipment for managing a likely difficult upper airway must also be immediately available in critical care or specialist locations and be able to be brought to the bed-side in other clinical areas. This should include a range of locally agreed facemasks, oral or nasal adjuncts, laryngoscope blades, videolaryngoscopes, fibreoptic or rigid endoscopes, supraglottic airway devices and equipment for front-of-neck access [55, 79, 80]. Similarly, anaesthetic drugs must be available; immediately in critical care areas and a system in place to deliver them rapidly to the bed-side elsewhere within a hospital [88, 89]. It may be appropriate to move the patient to a more specialist area such as the operating theatre or intensive care unit.

Suction to assess tracheostomy patency

The basic response to assessing tracheostomy patency continues by firstly removing any external attachments from the tracheostomy tube. This should include temporary disconnection from a ventilator circuit to exclude problems with the circuit tubing or the ventilator itself. Ancillary devices include heat and moisture exchange (HME) filters, decannulation caps and speaking valves, all of which can become blocked with blood or secretions during routine use [90].

Inner cannulae contribute to reduced incidence of tracheostomy tube blockage as part of a package of care [71, 91], but will most likely only be present in tracheostomies of older children owing to the resulting reduced internal diameter. If present, the inner cannula should be removed. Some inner cannulae need to be replaced in order to connect the tracheostomy tube to an anaesthetic breathing circuit [55].

Successful and easy passage of a suction catheter through the tracheostomy tube and into the trachea to the pre-determined length gives strong reassurance that the tube is at least partially patent and is sited within the airway [55]. Secretions that are present are suctioned and the ABCDE assessment continued. A partially obstructed tube may still need to be replaced. We do not recommend using a bougie or a similar rigid device to assess tube patency as if the tube is partially or completely displaced from the airway, these stiffer devices are more likely to create a false passage [92, 93]. Soft-tipped suction catheters will not advance significantly into the soft tissues [94, 95].

If the suction catheter cannot be passed easily to the pre-determined depth indicated on the bedhead sign, then the tracheostomy is likely blocked or displaced.

Emergency tracheostomy tube change

As detailed above, maturation sutures promote early stomal maturation and are the rationale behind

attempting an emergency tracheostomy tube change before attempting upper airway management in these guidelines. A blocked or partially displaced tracheostomy tube can be considered as a foreign body in the trachea that must be removed. We recommend an emergency tracheostomy tube change if initial assessment demonstrates a lack of tracheostomy tube patency. An immediate attempt at re-insertion is also applicable if the tube has become completely displaced from the neck, unless the child was being considered for a trial of decannulation. If stay sutures are present then they should both be elevated by hand, lifting them 'up and out'. Some staff may be reluctant to remove a tracheostomy tube, especially if the child has a known difficult upper airway. However, when faced with a deteriorating patient and an obstructed airway, a non-functioning tracheostomy tube offers no benefit, with considerable potential for harm [96, 97]. By considering a blocked or displaced tracheostomy tube as a foreign body within the airway, improvement can be anticipated upon removal.

We recommend that for the first emergency tube change, a tracheostomy tube of the same size as the one removed is used [61, 98]. For this first tube change we do not recommend using an exchange guide such as a bougie, wire or suction catheter, as the existing tube is likely blocked, or displaced from its intended position. We recommend the use of a dedicated obturator which may ease insertion, reduce trauma and protect the stoma [60, 92, 99, 100]. If the replacement tube appears to be inserted successfully, we recommend a clinical assessment of patency as described above, supported by waveform capnography if available. If the child has reduced or absent respiratory effort, clinical assessment of patency is more difficult. Easy passage of a suction catheter through the new tube to the depth indicated on the bedhead sign implies airway patency and, following this assessment, an experienced responder may elect gentle hand ventilation via the tracheostomy tube in the absence of spontaneous respiration. We do not recommend attempts at ventilation if a suction catheter will not easily pass as there is a significant risk of causing subcutaneous emphysema if the tube has entered a false passage (Fig. 5) [82, 83, 96].

If the first attempt at replacement is unsuccessful, a second emergency tube change should be performed with a tube one half-size smaller, again followed by assessing for airway patency [61, 96, 98]. Using a tube that is one half-size smaller than the original may make insertion easier and as the tube is smaller in length, the tip may then sit above any partial obstruction or granuloma in the trachea. Changing the child's position may be helpful, further extending the neck to bring the trachea anteriorly with a pillow or towel under the shoulders (Fig. S2) [60]. A new tracheostomy will have stay sutures which can be used to aid re-insertion by widening the stoma and bringing the trachea anteriorly [18, 39].

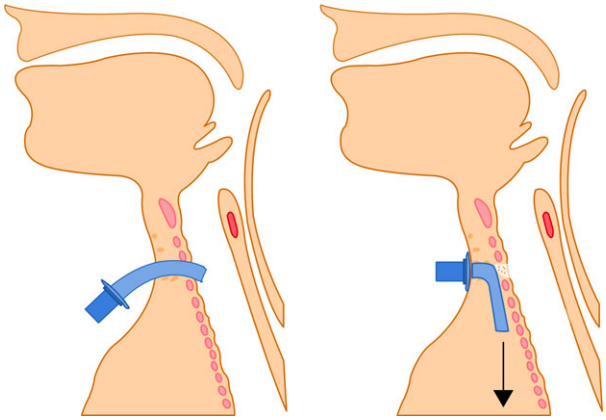

Figure 5 A partially displaced uncuffed tracheostomy tube (left) and a tube that has entered a false passage in the tissues of the neck, anterior to the trachea (right).

If the second attempt at replacement is unsuccessful, we recommend a third attempt using a soft suction catheter to guide placement, much like a Seldinger technique [60, 92]. This attempt should be made using a tube that is one half-size smaller than the original tube and with attention to positioning as above. Use of this third step will depend on the clinical situation, location of the patient, availability of other equipment, and any bleeding from or swelling of the stoma site. This technique has been preferred by rural and community practitioners with limited options available in an emergency [60].

Difficulties replacing the tube can be varied due to structural airway anomalies (trachea-bronchomalacia, false tract, scar tissue), a distressed child or spasm of the surrounding tissues, narrowing the stoma site.

Patency of an apparently successfully inserted tube should be assessed clinically as described above. If the replacement tube is not patent then it must be removed. If the replacement tube cannot be inserted after three attempts, we do not recommend further attempts at insertion.

Assessment of breathing and rescue breaths

The assessment of tracheostomy tube patency after attempts to (re)insert a new tube should also include assessment of the upper airway for spontaneous

ventilation. If the patient is breathing spontaneously via the nose/mouth or tracheostomy tube or open stoma, then oxygen should be applied to that site, or both sites. If the child is improving then a clinical decision needs to be made about the best people, equipment and location to secure a definitive airway and the urgency of management.

If there are no signs of breathing, then an assessment for 'signs of life' and a pulse check should occur. Cardiopulmonary resuscitation should follow routine Advanced Paediatric Life Support guidelines, ensuring that advanced help, resuscitation teams or an ambulance has been called as appropriate [79]. The following 'advanced response' section of these guidelines should be utilised during resuscitation to aid with management of airway and breathing, as a blocked or displaced tracheostomy could have been a cause of hypoxia and the cardiorespiratory deterioration.

We recommend attempting to deliver five rescue breaths to the child if they are not breathing, or spontaneous ventilation is inadequate at this point. This may be evidenced by cyanosis, low oxygen saturations, bradycardia, clinical signs of respiratory distress or obstruction, or an unresponsive child. Rescue breaths should be delivered using high flow oxygen where possible, although mouth-to-mouth or mouth-to-tracheostomy ventilation has been described [101].

If the child has a patent upper airway, rescue breaths should be delivered via a facemask. If the upper airway is obstructed, then these should be delivered via the stoma. Effectiveness of ventilation should be judged clinically, supported by waveform capnography where possible [85, 102]. Techniques are discussed in detail in the next sections.

Primary emergency oxygenation

There are essentially two airway options to consider for emergency oxygenation: either via the mouth or via the tracheostomy stoma. Information from the bedhead sign will guide responders as to which airway is likely to be easier, and the clinical experience of the responders may also influence which airway they are more comfortable managing. We recommend a graded response to managing the airway: responders are first guided to use the least invasive techniques that have the highest likelihood of success. More invasive techniques have higher complication rates and although these may be required to ultimately 'secure' the airway, less invasive techniques may facilitate re-oxygenation to allow safer definitive airway management.

Standard oral airway manoeuvres may be appropriate and are familiar to most clinical staff. We recommend standard management as for any patient who is not breathing such as bag-valve masks, oral or nasal airway adjuncts and supraglottic airway devices (SAD) [103]. Second-generation SADs allow more effective ventilation at lower peak inflation pressures, offer a degree of separation between the oesophagus and trachea which may reduce the aspiration risk, and may be easier to insert and secure [104, 105]. Supraglottic airway devices have been successfully used in the emergency and out-of-hospital environments in children [106, 107]. The stoma must be occluded to prevent air escaping via the neck, which would reduce the effectiveness of ventilation. We recommend the use of a gloved finger or non-woven ('surgical') gauze for occluding the stoma.

If ventilation via the upper airways is not possible or inadequate, ventilation may be attempted via the stoma. We recommend using a paediatric facemask or SAD such as a LMA® laryngeal mask[1] applied over the stoma [108] attached to a bag-valve mask (Fig. 6). The upper airway may need to be closed to facilitate effective ventilation via the stoma.

If non-invasive primary measures fail to oxygenate the child, more invasive secondary techniques may be required. Intubation may be achieved via the upper airway using standard techniques, recognising that the incidence of difficult airways in children with tracheostomies is high [80]. Difficult SAD ventilation and facemask ventilation are both known to be more common after failed intubation, increasing the likelihood of progression to a can't-intubate, can't-oxygenate (CICO) scenario [109]. Responders should prepare for difficulty in intubation and consideration of operator, environment and equipment must be made. This is especially important if sedative or neuromuscular blocking drugs are administered. We recommend that the first attempt at translaryngeal intubation be made with an tracheal tube one half-size smaller than the original tracheostomy tube. An uncut tracheal tube can be carefully advanced beyond the stoma in patients with a patent upper airway [55]. Micro-cuffed tracheal tubes may be used. Appropriate sizes should be indicated on the bedhead sign.

If intubation of the upper airway is known to be impossible or fails, we recommend attempting intubation of the tracheostomy stoma itself using a tracheal tube one half-size smaller than the original tracheostomy tube [110, 111]. This may be a simple, temporary, yet life-saving alternative where

[1]LMA is a registered trade mark of The Laryngeal Mask Company Ltd, an affiliate of Teleflex Incorporated.

Figure 6 Paediatric facemask (left) and supraglottic airway device (right) applied to an infant's stoma can provide effective oxygenation and ventilation.

tracheostomy tube insertion has failed and is especially useful in an emergency [112]. Translaryngeal intubation of the trachea or intubation of the stoma may be assisted by specialist equipment such as videolaryngoscopes, fibreoptic or rigid endoscopes, guidewires or airway exchange catheters [74, 113, 114].

If intubation of the upper airway or stoma is not successful and the child cannot be oxygenated by the face or stoma, this CICO situation should be explicitly declared to the attending team. This is a desperate situation and cardiac arrest should be anticipated. Options at this point include:

- Further attempts or advanced or assisted intubation of the upper airway or stoma by more experienced responders using specialised equipment [115]
  - Intubation endoscopes (e.g. Bonfils™, Bambrink™)
  - Hopkins rod lens-telescope
  - Flexible fiberoptic endoscopes
- Attempted cricothyroidotomy
- Emergency surgical exploration of the stoma and attempts at percutaneous or surgical tracheostomy [116, 117]
- Extracorporeal membrane oxygenation may be possible in some units [118, 119]

Following emergency re-intubation of the upper airway or stoma, waveform capnography should be used to confirm tracheal placement. Clinical examination may identify accidental endobronchial placement, but is insensitive and airway endoscopy or chest X-ray may be required [120, 121]. Pharyngeal or oesophageal injury may have occurred [122].

Special circumstances

Tracheostomy bleeding can be immediate, early or late in presentation and can be minor, moderate or life threatening. Causes include traumatic suctioning, granulomata, local infection, bleeding disorders and rarely (but frequently fatal) haemorrhage from tracheo-arterial fistulae. Minor bleeding can be managed in a conservative manner with careful observation; most usually settle with no surgical intervention. Tracheo-arterial fistulae should be suspected with moderate bleeding from the stomal site or pulsation of the tracheostomy tube. A sentinel bleed is reported in around one half of cases [123]. If suspected, a tracheostomy tube cuff should be (hyper)inflated, if present. Alternatively, intubation of the stoma using a cuffed tracheal tube maybe required, with the tube tip placed distal to the fistula. Pressure may be applied via a hyperinflated cuff or digitally, either directly or applied to the innominate artery site. Standard resuscitation measures should occur in tandem and emergency plans made for definitive surgical treatment, which is usually ligation of the innominate artery [124].

Fractured paediatric tracheostomy tubes are rarely reported [111, 125, 126]. There are specific susceptible points at the junction of the tube and the neck plate, the distal end of the tube and the fenestration site [127]. They can present as an airway foreign body and should preferably be removed using a bronchoscopic technique.

Discussion

The purpose of this paper is to provide clear, practical guidance in preparing for, recognising and managing common tracheostomy emergencies that occur in paediatric patients. Much like existing guidelines for airway management or cardiopulmonary resuscitation, these standardised management plans are directly transferable between hospitals and locations in which children with tracheostomies may be managed [66, 80, 128]. The guidelines are directed at multidisciplinary responders who may not be airway or tracheostomy experts, recognising that some staff may have specialist skills that compliment or enhance the strategies described.

While complications from airway and tracheostomy management are infrequent, the consequences can be significant for the patient, family, responding teams and institutions, ranging from unnecessary or preventable admissions to significant harm and death [68, 129].

However, published literature concerning airway complications and management strategies in children is limited, especially regarding tracheostomies. While these guidelines, therefore, represent expert opinion based on the available evidence, external advice has been sought and considered from individuals and from relevant stakeholder organisations.

Paediatric tracheostomy patients are a transient population, being managed in tertiary and community hospitals and environments, requiring a variety of hospital-based procedures, and represent a distinctly different population to adults with tracheostomies, meriting separate guidelines. The principles of providing emergency oxygenation and limiting the number of unnecessary airway interventions are retained from the adult guidelines, but key differences include:

- Bespoke paediatric bedhead signs reflecting paediatric tracheostomy indications and pathologies
- Recognition of (almost) exclusively surgical tracheostomies with stay sutures and maturation sutures available to aid emergency management
- Initial management includes up to three attempts at emergency tracheostomy tube changes
- Use of suction catheters to guide re-insertion

Existing guidance suggests that healthcare professionals who look after children with tracheostomies should receive regular training in routine and emergency airway management [3, 4]. While patients are increasingly complex and require the input of multidisciplinary teams and healthcare professionals, we hope that the publication of these guidelines will support standardised training for multidisciplinary staff [29]. Standardised, structured educational programmes are also of benefit to parents and carers and may have a positive impact on carer confidence and patient safety in the community [16, 75, 130, 131]. The NTSP has developed e-learning, resources and courses to support these guidelines (www.tracheostomy.org.uk).

While the primary aim of these guidelines is to improve the emergency management of paediatric tracheostomy emergencies, wider developments include addressing the safety and quality of care, with the aim of reducing the incidence of airway emergencies. Initiatives such as the Global Tracheostomy (Quality Improvement) Collaborative (www.globaltrach.org) can support organisational improvements and by collecting patient-level metrics, quantify the effectiveness of care bundles, protocols, and of training, equipping and supporting staff in delivering high-quality care [63, 132–134]. Improving transitional and community paediatric tracheostomy care may also improve the safety and quality of care and reduce emergency department visits [130, 135]. These multidisciplinary guidelines for the management of paediatric tracheostomy emergencies are an important element of improving tracheostomy care.

Acknowledgements

We are grateful to the following organisations who have supported the development of these guidelines and approved this manuscript and algorithm: Advanced Life Support Group; Association of Paediatric Anaesthetists; British Association of Paediatric Otolaryngologists; Global Tracheostomy Collaborative; Paediatric Intensive Care Society; The Resuscitation Council (UK); Royal College of Paediatrics and Child Health.

The project has not been directly funded, although the NTSP has supported some meeting costs. The NTSP is a charity registered in England & Wales (1160824). BM has received expenses from Smiths-Medical and Ambu for attending company educational and product evaluation events, for which he has declined personal payment. BM is currently NHS England National Clinical Advisor for Tracheostomy and European lead of the Global Tracheostomy Collaborative.

References

1. Trachsel D, Hammer J. Indications for tracheostomy in children. *Paediatric Respiratory Reviews* 2006; **7**: 162–8.
2. Overman AE, Liu M, Kurachek SC, et al. Tracheostomy for infants requiring prolonged mechanical ventilation: 10 years' experience. *Pediatrics* 2013; **131**: e1491–e1496.
3. de Trey L, Niedermann E, Ghelfi D, Gerber A, Gysin C. Pediatric tracheotomy: a 30-year experience. *Journal of Pediatric Surgery* 2013; **48**: 1470–5.
4. Campisi P, Forte V. Pediatric tracheostomy. *Seminars in Pediatric Surgery* 2016; **25**: 191–5.
5. Wakeham MK, Kuhn EM, Lee KJ, McCrory MC, Scanlon MC. Use of tracheostomy in the PICU among patients requiring prolonged mechanical ventilation. *Intensive Care Medicine* 2014; **40**: 863–70.
6. Lawrason A, Kavanagh K. Pediatric tracheotomy: are the indications changing? *International Journal of Pediatric Otorhinolaryngology* 2013; **77**: 922–5.
7. Moldenhauer JS. Ex utero intrapartum therapy. *Seminars in Pediatric Surgery* 2013; **22**: 44–9.
8. Hospital Episode Statistics. Procedures in England 2014–15. 2015. www.hsic.gov.uk. (accessed 21/01/2017).
9. Ogilvie LN, Kozak JK, Chiu S, Adderley RJ, Kozak FK. Changes in pediatric tracheostomy 1982–2011: a Canadian

tertiary children's hospital review. *Journal of Pediatric Surgery* 2014; **49**: 1549–53.
10. Crysdale WS, Feldman RI, Naito K. Tracheotomies: a 10-year experience in 319 children. *Annals of Otolology, Rhinology and Laryngology* 1988; **97**: 439–43.
11. Lewis CW, Carron JD, Perkins JA, Sie KCY, Feudtner C. Tracheotomy in pediatric patients: a national perspective. *Archives of Otolaryngology - Head and Neck Surgery* 2003; **129**: 523–9.
12. Tucker JA, Silberman HD. Tracheotomy in pediatrics. *Annals of Otolology, Rhinology and Laryngology* 1972; **81**: 818–24.
13. Tsuboi N, Ide K, Nishimura N, Nakagawa S, Morimoto N. Pediatric tracheostomy: survival and long-term outcomes. *International Journal of Pediatric Otorhinolaryngology* 2016; **89**: 81–5.
14. Özmen S, Özmen ÖA, Ünal ÖF. Pediatric tracheotomies: a 37-year experience in 282 children. *International Journal of Pediatric Otorhinolaryngology* 2009; **73**: 959–61.
15. McCormick ME, Ward E, Roberson DW, Shah RK, Stachler RJ, Brenner MJ. Life after tracheostomy: patient and family perspectives on teaching, transitions, and multidisciplinary teams. *Otolaryngology Head and Neck Surgery* 2015; **153**: 914–20.
16. Hopkins C, Whetstone S, Foster T, Blaney S, Morrison G. The impact of paediatric tracheostomy on both patient and parent. *International Journal of Pediatric Otorhinolaryngology* 2009; **73**: 15–20.
17. Schweiger C, Manica D, Becker CF, et al. Tracheostomy in children: a ten-year experience from a tertiary center in southern Brazil. *Brazilian Journal of Otorhinolaryngology* 2016; **31**: 1–6.
18. Craig MF, Bajaj Y, Hartley BEJ. Maturation sutures for the paediatric tracheostomy – an extra safety measure. *Journal of Laryngology and Otology* 2005; **119**: 985–7.
19. Gollu G, Ates U, Can OS, et al. Percutaneous tracheostomy by Griggs technique under rigid bronchoscopic guidance is safe and feasible in children. *Journal of Pediatric Surgery* 2016; **51**: 1635–9.
20. Zawadzka-Glos L, Rawicz M, Chmielik M. Percutaneous tracheotomy in children. *International Journal of Pediatric Otorhinolaryngology* 2004; **68**: 1387–90.
21. McGrath BA, Wilkinson KA. The NCEPOD study: on the right trach? lessons for the anaesthetist. *British Journal of Anaesthesia* 2015; **115**: 155–8.
22. Wood D, McShane P, Davis P. Tracheostomy in children admitted to paediatric intensive care. *Archives of Diseases in Childhood* 2012; **97**: 866–9.
23. Sherman JM, Davis S, Albamonte-Petrick S, et al. Care of the child with a chronic tracheostomy. *American Journal of Respiratory and Critical Care Medicine* 2000; **161**: 297–308.
24. Martin IC, Freeth H, Kelly K, Mason M. NCEPOD: on the right Trach? 2014. www.ncepod.org.uk/2014tc.htm. (accessed 20/10/2015).
25. Eibling DE, Roberson DW. Managing tracheotomy risk: time to look beyond hospital discharge. *Laryngoscope* 2012; **122**: 23–4.
26. Halum SL, Ting JY, Plowman EK, et al. A multi-institutional analysis of tracheotomy complications. *Laryngoscope* 2012; **122**: 38–45.
27. Doherty C, McGrath BA. Quality of tracheostomy care is probably as important as timing. *British Journal of Anaesthesia* 2016; **116**: 300.
28. Das P, Zhu H, Shah RK, Roberson DW, Berry J, Skinner ML. Tracheotomy-related catastrophic events: results of a national survey. *Laryngoscope* 2012; **122**: 30–7.
29. Liu C, Heffernan C, Saluja S, et al. Indications, hospital course, and complexity of patients undergoing tracheostomy at a tertiary care pediatric hospital. *Otolaryngology Head and Neck Surgery* 2014; **151**: 232–9.
30. Mahida JB, Asti L, Boss EF, et al. Tracheostomy placement in children younger than 2 years: 30-day outcomes using the national surgical quality improvement program. *Otolaryngology Head and Neck Surgery* 2016; **142**: 241–6.
31. Holscher CM, Stewart CL, Peltz ED, et al. Early tracheostomy improves outcomes in severely injured children and adolescents. *Journal of Pediatric Surgery* 2014; **49**: 590–2.
32. Dal'Astra APL, Quirino AV, de Sousa Caixêta JA, Avelino MAG. Tracheostomy in childhood: review of the literature on complications and mortality over the last three decades. *Brazilian Journal of Otorhinolaryngology* 2017; **83**: 207–14.
33. Pérez-Ruiz E, Caro P, Pérez-Frías J, et al. Paediatric patients with a tracheostomy: a multicentre epidemiological study. *European Respiratory Journal* 2012; **40**: 1502–7.
34. Lee JH, Smith PB, Quek MBH, Laughon MM, Clark RH, Hornik CP. Risk factors and in-hospital outcomes following tracheostomy in infants. *Journal of Pediatrics* 2016; **173**: 39–44.
35. Funamura JL, Yuen S, Kawai K, et al. Characterizing mortality in pediatric tracheostomy patients. *Laryngoscope* 2017; **127**: 1701–6.
36. Watters K, O'Neill M, Zhu H, Graham RJ, Hall M, Berry J. Two-year mortality, complications, and healthcare use in children with medicaid following tracheostomy. *Laryngoscope* 2016; **126**: 2611–17.
37. McGrath BA, Wilkinson K, Shah RK. Notes from a Small Island: lessons from the UK NCEPOD tracheotomy report. *Otolaryngology – Head and Neck Surgery* 2015; **153**: 167–9.
38. Alladi A, Rao S, Das K, Charles AR, D'Cruz AJ. Pediatric tracheostomy: a 13-year experience. *Pediatric Surgery International* 2004; **20**: 695–8.
39. Colman KL, Mandell DL, Simons JP. Impact of stoma maturation on pediatric tracheostomy-related complications. *Archives of Otolaryngology Head and Neck Surgery* 2010; **136**: 471–4.
40. Shah RK, Stey AM, Jatana KR, Rangel SJ, Boss EF. Identification of opportunities for quality improvement and outcome measurement in pediatric otolaryngology. *Otolaryngology Head and Neck Surgery* 2014; **140**: 1019–8.
41. Song J-J, Choi IJ, Chang H, et al. Pediatric tracheostomy revisited: a nine-year experience using horizontal intercartilaginous incision. *Laryngoscope* 2014; **125**: 485–92.
42. Douglas CM, Poole-Cowley J, Morrissey S, Kubba H, Clement WA, Wynne D. Paediatric tracheostomy – an 11 year experience at a Scottish paediatric tertiary referral centre. *International Journal of Pediatric Otorhinolaryngology* 2015; **79**: 1673–6.
43. D'Souza JN, Levi JR, Park D, Shah UK. Complications following pediatric tracheotomy. *Otolaryngology Head and Neck Surgery* 2016; **142**: 484–8.
44. Gianoli GJ, Miller RH, Guarisco JL. Tracheotomy in the first year of life. *Annals of Otology, Rhinology and Laryngology* 1990; **99**: 896–901.
45. DeMauro SB, D'Agostino JA, Bann C, et al. Developmental outcomes of very preterm infants with tracheostomies. *Journal of Pediatrics* 2014; **164**: 1303–10.
46. Mortimer H, Kubba H. A retrospective case series of 318 tracheostomy-related adverse events over 6 years- a Scottish context. *Clinical Otolaryngology* 2017; **42**: 936–40.
47. Wilcox LJ, Weber BC, Cunningham TD, Baldassari CM. Tracheostomy complications in institutionalized children with

long-term tracheostomy and ventilator dependence. *Otolaryngology Head and Neck Surgery* 2016; **154**: 725–30.
48. Farida JP, Lawrence LA, Svider PF, et al. Protecting the airway and the physician: aspects of litigation arising from tracheotomy. *Head and Neck* 2015; **38**: 751–4.
49. Smith-Miller C. Graduate nurses' comfort and knowledge level regarding tracheostomy care. *Journal for Nurses in Staff Development* 2006; **22**: 222–9.
50. McGrath BA, Thomas AN. Patient safety incidents associated with tracheostomies occurring in hospital wards: a review of reports to the UK National Patient Safety Agency. *Postgraduate Medical Journal* 2010; **86**: 522–5.
51. Thomas AN, McGrath BA. Patient safety incidents associated with airway devices in critical care: a review of reports to the UK National Patient Safety Agency. *Anaesthesia* 2009; **64**: 358–65.
52. Cook TM, Woodall N, Frerk C. On behalf of the Fourth National Audit Project. Major complications of airway management in the UK: results of the Fourth National Audit Project of the Royal College of Anaesthetists and the Difficult Airway Society. Part 1: anaesthesia. *British Journal of Anaesthesia* 2011; **106**: 617–31.
53. McGrath BA, Calder N. Tracheostomy and laryngectomy emergency management – implications for critical care. *Clinical Otolaryngology* 2013; **38**: 541–5.
54. Templeton R, Webster K, McGrath BA. Patient safety incidents associated with displaced or obstructed tracheostomies: comparison of levels of harm between critical care and ward environments. *British Journal of Anaesthesia* 2011; **107**: 834–5.
55. McGrath BA, Bates L, Atkinson D, Moore JA. Multidisciplinary guidelines for the management of tracheostomy and laryngectomy airway emergencies. *Anaesthesia* 2012; **67**: 1025–41.
56. Doherty C, Bowler M, Monks S, et al. Reduction in harm from tracheostomy related incidents after implementation of the paediatric National Tracheostomy Safety Project resources: a retrospective analysis from a tertiary paediatric centre. *Clinical Otolaryngology* 2017; **43**: 674–8.
57. Eber E, Oberwaldner B. Tracheostomy care in the hospital. *Paediatric Respiratory Reviews* 2006; **7**: 175–84.
58. Hettige R, Arora A, Roberson DW, Narula AA. Recent developments to improve the standards of tracheostomy care. *British Journal of Intensive Care* 2013; **23**: 89–92.
59. Doherty C, Atkinson D, Bruce I, et al. Targeted training using paediatric tracheostomy emergency algorithm improves performance in simulated scenarios. *British Journal of Anaesthesia* 2015; **115**: e950–62.
60. Great Ormond Street Hospital Clinical Guidelines. Tracheostomy care and management. 2015. http://www.gosh.nhs.uk/health-professionals/clinical-guidelines/tracheostomy-care-and-management-review (accessed 22/01/2017).
61. Mitchell RB, Hussey HM, Setzen G, et al. Clinical consensus statement: tracheostomy care. *Otolaryngology – Head and Neck Surgery* 2013; **148**: 6–20.
62. NHS Scotland. Caring for the child/young person with a tracheostomy. 2008. http://www.healthcareimprovementscotland.org/previous_resources/best_practice_statement/tracheostomy_care_in_children.aspx (accessed 22/01/2017).
63. Lippert D, Hoffman MR, Dang P, McMurray JS, Heatley D, Kille T. Care of pediatric tracheostomy in the immediate postoperative period and timing of first tube change. *International Journal of Pediatric Otorhinolaryngology* 2014; **78**: 2281–5.
64. Gluth MB, Maska S, Nelson J, Otto RA. Postoperative management of pediatric tracheostomy: results of a nationwide survey. *Otolaryngology – Head and Neck Surgery* 2000; **122**: 701–5.
65. Santoro AS, Cooper MG, Cheng A. Failed intubation and failed oxygenation in a child. *Anaesthesia and Intensive Care Medicine* 2012; **40**: 1056–8.
66. Frerk C, Mitchell VS, McNarry AF, et al. Difficult Airway Society 2015 guidelines for management of unanticipated difficult intubation in adults. *British Journal of Anaesthesia* 2015; **115**: 827–48.
67. Higgs A, Cook TM, McGrath BA. Airway management in the critically ill: the same, but different. *British Journal of Anaesthesia* 2016; **117**: i5–9.
68. Kanthimathinathan HK, Durward A, Nyman A, Murdoch IA, Tibby SM. Unplanned extubation in a paediatric intensive care unit: prospective cohort study. *Intensive Care Medicine* 2015; **41**: 1299–306.
69. National Patient Safety Agency. Protecting patients who are neck breathers (Patient safety information leaflet 0149). 2005. http://www.nrls.npsa.nhs.uk/resources/?EntryId45=59793 (accessed 20/09/2017).
70. Difficult Airway Society. Airway alert form. 2017. http://www.das.uk.com/guidelines/downloads.html (accessed 20/09/2017).
71. Intensive Care Society. Standards for the care of adult patients with a temporary Tracheostomy. 2014. http://www.ics.ac.uk (accessed 20/09/2017).
72. Wilson M. Tracheostomy management. *Paediatric Nursing* 2005; **17**: 38–43.
73. Tweedie DJ, Skilbeck CJ, Cochrane LA, Cooke J, Wyatt M. Choosing a paediatric tracheostomy tube: an update on current practice. *Journal of Laryngology and Otology* 2008; **122**: 161–9.
74. Rajendram R, McGuire N. Repositioning a displaced tracheostomy tube with an Aintree intubation catheter mounted on a fibre-optic bronchoscope. *British Journal of Anaesthesia* 2006; **97**: 576–9.
75. Flynn AP, Carter B, Bray L, Donne AJ. Parents' experiences and views of caring for a child with a tracheostomy: a literature review. *International Journal of Pediatric Otorhinolaryngology* 2013; **77**: 1630–4.
76. Henderson JJ, Popat MT, Latto IP, Pearce AC, Difficult Airway Society. Difficult Airway Society guidelines for management of the unanticipated difficult intubation. *Anaesthesia* 2004; **59**: 675–94.
77. Arora A, Hettige R, Ifeacho S, Narula A. Driving standards in tracheostomy care: a preliminary communication of the St Mary's ENT-led multi disciplinary team approach. *Clinical Otolaryngology* 2008; **33**: 596–9.
78. McGrath BA. *Comprehensive tracheostomy care: the national tracheostomy safety project manual*. London: Wiley, 2014.
79. Advanced Life Support Group. *Advanced paediatric life support: a practical approach to emergencies*. London: Wiley Blackwell, 2016.
80. Black AE, Flynn PER, Smith HL, Thomas ML, Wilkinson KA. Development of a guideline for the management of the unanticipated difficult airway in pediatric practice. *Pediatric Anesthesia* 2015; **25**: 346–62.
81. Arai Y-CP, Fukunaga K, Ueda W, Hamada M, Ikenaga H, Fukushima K. The endoscopically measured effects of airway maneuvers and the lateral position on airway patency in anesthetized children with adenotonsillar hypertrophy. *Anesthesia and Analgesia* 2005; **100**: 949–52.
82. van Heurn LW, Welten RJ, Brink PR. A complication of percutaneous dilatational tracheostomy: mediastinal emphysema. *Anaesthesia* 1996; **51**: 605.
83. Showmaker JA, Page MP. Life-threatening tension subcutaneous emphysema as a complication of open tracheostomy. *Otolaryngology – Head and Neck Surgery* 2010; **142**: 628–9.

84. Doherty GM. Acute and chronic airway obstruction in children. *Anaesthesia and Intensive Care Medicine* 2009; **10**: 191–5.
85. Whitaker DK, Benson JP. Capnography standards for outside the operating room. *Current Opinion in Anaesthesiology* 2016; **29**: 485–92.
86. Langhan ML, Li F-Y, Lichtor JL. The impact of capnography monitoring among children and adolescents in the postanesthesia care unit: a randomized controlled trial. *Pediatric Anesthesia* 2017; **27**: 385–93.
87. Cook TM, Woodall N, Frerk C. A national survey of the impact of NAP4 on airway management practice in United Kingdom hospitals: closing the safety gap in anaesthesia, intensive care and the emergency department. *British Journal of Anaesthesia* 2016; **117**: 182–90.
88. Paediatric Intensive Care Society Standards. 5th Edition. 2015. http://picsociety.uk/wpcontent/uploads/2016/05/PICS_standards_2015.pdf (accessed 12/02/2017).
89. Royal College of Paediatrics and Child Health. Standards for children and young people in emergency care settings. 2012. http://www.rcpch.ac.uk/sites/default/files/page/Intercollegiate%20Emegency%20Standards%202012%20FINAL%20WEB.pdf (accessed 13/02/2017).
90. Buswell C, Powell J, Powell S. Paediatric tracheostomy speaking valves: our experience of forty-two children with an adapted Passy-Muir speaking valve. *Clinical Otolaryngology* 2017; **42**: 941–4.
91. Björling G, Belin A-L, Hellström C, et al. Tracheostomy inner cannula care: a randomized crossover study of two decontamination procedures. *American Journal of Infection Control* 2007; **35**: 600–5.
92. Lyons MJ, Cooke J, Cochrane LA, Albert DM. Safe reliable atraumatic replacement of misplaced paediatric tracheostomy tubes. *International Journal of Pediatric Otorhinolaryngology* 2007; **71**: 1743–6.
93. Young CS. A review of the adverse effects of airway suction. *Physiotherapy* 1984; **70**: 104–8.
94. Lomholt N. Design and function of tracheal suction catheters. *Acta Anaesthesiolica Scandaninavica* 1982; **26**: 1–3.
95. Glass CA, Grap MJ. Ten tips for safer suctioning. *American Journal of Nursing* 1995; **95**: 51–3.
96. Seay SJ, Gay SL. Problem in tracheostomy patient care: recognizing the patient with a displaced tracheostomy tube. *ORL Head and Neck Nursing* 1997; **15**: 10–11.
97. Rauf K, Zwaal JW. Accidental decannulation after surgical tracheostomy. *Anaesthesia* 2004; **59**: 517–7.
98. O'Connor HH, White AC. Tracheostomy decannulation. *Respiratory Care* 2010; **55**: 1076–81.
99. Johns Hopkins Medicine Tracheostomy Service. Difficulty inserting the new tracheostomy tube. https://www.hopkinsmedicine.org/tracheostomy/living/change_problem.html (accessed 21/09/2017).
100. Posner JC. Acute care of the child with a tracheostomy. *Pediatric Emergency Care* 1999; **15**: 49–54.
101. American Heart Association. American heart association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care: pediatric basic life support. *Circulation* 2005; **112**: 156–66.
102. Association of Anaesthetists of Great Britain and Ireland. Recommendations for standards of monitoring during anaesthesia and recovery. *Anaesthesia* 2016; **71**: 85–93.
103. Umutoglu T, Gedik AH, Bakan M, et al. The influence of airway supporting maneuvers on glottis view in pediatric fiberoptic bronchoscopy. *Brazilian Journal of Anesthesiology (English Edition)* 2015; **65**: 313–18.
104. Woodall NM, Cook TM. National census of airway management techniques used for anaesthesia in the UK: first phase of the Fourth National Audit Project at the Royal College of Anaesthetists. *British Journal of Anaesthesia* 2011; **106**: 266–71.
105. Bradley AED, White MC, Engelhardt T, Bayley G, Beringer RM. Current UK practice of pediatric supraglottic airway devices – a survey of members of the Association of Paediatric Anaesthetists of Great Britain and Ireland. *Pediatric Anesthesia* 2013; **23**: 1006–9.
106. Ostermayer DG, Gausche-Hill M. Supraglottic airways: the history and current state of prehospital airway adjuncts. *Prehospital Emergency Care* 2014; **18**: 106–15.
107. Chen L, Hsiao AL. Randomized trial of endotracheal tube versus laryngeal mask airway in simulated prehospital pediatric arrest. *Pediatrics* 2008; **122**: e294–7.
108. Ushiroda J, Inoue S, Furuya H, Kawaguchi M. [Effective use of laryngeal mask airway to stop a supraglottic air leak which prevented adequate ventilation via a tracheostomy in a pediatric patient]. *Masui* 2013; **62**: 1360–1.
109. Kheterpal S, Martin L, Shanks AM, Tremper KK. Prediction and outcomes of impossible mask ventilation: a review of 50,000 anesthetics. *Anesthesiology* 2009; **110**: 891–7.
110. Shiber JR, Fontane E. Digital tracheal intubation: an effective technique that should not be forgotten. *American Journal of Emergency Medicine* 2007; **25**: 726.
111. Gupta SL, Swaminathan S, Ramya R, Parida S. Fractured tracheostomy tube presenting as a foreign body in a paediatric patient. *BMJ Case Reports* 2016 Mar 8; bcr-2015-213963. http://casereports.bmj.com/content/2016/bcr-2015-213963.abstract (accessed 23/02/2017).
112. Kurien M, Raviraj R, Mathew J, Kaliaperumal I, Ninan S. Modified endotracheal tube: emergency alternative to paediatric tracheostomy tube. *Journal of Laryngology and Otology* 2011; **125**: 729–31.
113. Kaiser EF, Seschachar AM, Popovich MJ. Tracheostomy tube replacement: role of the airway exchange catheter. *Anesthesiology* 2001; **94**: 718–19.
114. Young JS, Brady WJ, Kesser B, Mullins D. A novel method for replacement of the dislodged tracheostomy tube: the nasogastric tube "guidewire" technique. *Journal of Emergency Medicine* 1996; **14**: 205–8.
115. Reilly BK, Volk MS. Emergency use of a customized tracheostomy tube for pediatric patients. *Laryngoscope* 2012; **122**: 1624–5.
116. Pracy JP, Brennan L, Cook TM, et al. Surgical intervention during a Can"t intubate Can"t Oxygenate (CICO) Event: emergency Front-of-neck Airway (FONA)? *British Journal of Anaesthesia* 2016; **117**: 426–8.
117. McCague A, Wong DT. Percutaneous dilational tracheostomy in the emergent setting. *International Journal of Clinical Medicine* 2013; **4**: 96–8.
118. Tyagi I, Goyal A, Syal R, Agarwal SK, Tewari P. Emergency cardiopulmonary bypass for impassable airway. *Journal of Laryngology and Otology* 2006; **120**: 687–90.
119. Ideno S, Shinto A, Matsuoka T, Miyazawa N, Yamamoto S. Two cases of emergency extracorporeal membrane oxygenation support in children suffering from tracheo-innominate artery fistula. *Masui* 2016; **65**: 146–9.
120. Yeo WX, Phua CQ, Lo S. Is routine chest X-ray after surgical and percutaneous tracheostomy necessary in adults: a systemic review of the current literature. *Clinical Otolaryngology* 2014; **39**: 79–88.
121. Genther DJ, Thorne MC. Utility of routine postoperative chest radiography in pediatric tracheostomy. *International Journal of Pediatric Otorhinolaryngology* 2010; **74**: 1397–400.
122. Peterson GN, Domino KB, Caplan RA, Posner KL, Lee LA, Cheney FW. Management of the difficult airway: a closed claims analysis. *Anesthesiology* 2005; **103**: 33.

123. Grant CA, Dempsey G, Harrison J, Jones T. Tracheo-innominate artery fistula after percutaneous tracheostomy: three case reports and a clinical review. *British Journal of Anaesthesia* 2006; **96**: 127–31.
124. Ghai B, Makkar J, Bakshi J, Rana S, Singh RS, Bhagat S. Survival of a child without sequelae after tracheoarterial fistula. *Pediatric Anesthesia* 2007; **17**: 588–91.
125. Parida PK, Kalaiarasi R, Gopalakrishnan S, Saxena SK. Fractured and migrated tracheostomy tube in the tracheobronchial tree. *International Journal of Pediatric Otorhinolaryngology* 2014; **78**: 1472–5.
126. Lynrah ZA, Goyal S, Goyal A, et al. Fractured tracheostomy tube as foreign body bronchus: our experience with three cases. *International Journal of Pediatric Otorhinolaryngology* 2012; **76**: 1691–5.
127. Gana PN, Takwoingi YM. Fractured tracheostomy tubes in the tracheobronchial tree of a child. *International Journal of Pediatric Otorhinolaryngology* 2000; **53**: 45–8.
128. Truhlář A, Deakin CD, Soar J, et al. European resuscitation council guidelines for resuscitation 2015: section 4. Cardiac arrest in special circumstances. *Resuscitation* 2015; **95**: 148–201.
129. Zhu H, Das P, Roberson DW, et al. Hospitalizations in children with pre-existing tracheostomy: a national perspective. *Laryngoscope* 2014; **125**: 462–8.
130. McGowin K. Decreasing emergency department visits and hospital admission in the pediatric tracheostomy population. *ORL Head and Neck Nursing* 2015; **33**: 6–9.
131. Gaudreau PA, Greenlick H, Dong T, et al. Preventing complications of pediatric tracheostomy through standardized wound care and parent education. *Otolaryngology – Head and Neck Surgery* 2016; **142**: 966–71.
132. McGrath BA, Lynch J, Bonvento B, et al. Evaluating the quality improvement impact of the Global Tracheostomy Collaborative in four diverse NHS hospitals. *BMJ Quality* 2017; **6**: bmjqir.u220636.w7996–9.
133. Lavin J, Shah R, Greenlick H, Gaudreau P, Bedwell J. The Global Tracheostomy Collaborative: one institution's experience with a new quality improvement initiative. *International Journal of Pediatric Otorhinolaryngology* 2016; **80**: 106–8.
134. Peña-López Y, Pujol M, Campins M, et al. Implementing a care bundle approach reduces ventilator-associated pneumonia and delays ventilator-associated tracheobronchitis in children: differences according to endotracheal or tracheostomy devices. *International Journal of Infectious Diseases* 2016; **52**: 43–8.
135. Abode KA, Drake AF, Zdanski CJ, Retsch-Bogart GZ, Gee AB, Noah TL. A multidisciplinary children's airway center: impact on the care of patients with tracheostomy. *Pediatrics* 2016; **137**: e20150455–5.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Figure S1. The paediatric tracheostomy bed-side emergency box, adapted from Great Ormond Street Hospital [60].

Figure S2. Assessment of the patency of the upper airway(s] and tracheostomy tube of an infant (left] and an older child (right). A rolled towel or small pillow placed under the infant's shoulders can assist with airway management, especially if aged under 2 years old.

Table S1. Suggested suction catheter size, insertion depths and suction pressure ranges for different sized tubes, grouped by approximate age ranges. Tubes detailed are available from Shiley™ (Medtronic, Minneapolis). Other manufacturers make similar tubes. (F – French Gauge).

Track Haemoglobin Changes in Real Time

Noninvasive and Continuous Haemoglobin (SpHb®) Trend Monitoring

Root® also offers analog view

SpHb trend monitoring may provide additional insight between invasive blood samples when:

- The SpHb trend is stable and the clinician may otherwise think haemoglobin is dropping
- The SpHb trend is rising and the clinician may otherwise think haemoglobin is not rising fast enough
- The SpHb trend is dropping and the clinician may otherwise think haemoglobin is stable

In a randomised trial involving 327 patients undergoing elective orthopaedic surgery, researchers found that the use of continuous SpHb monitoring reduced the rate of blood transfusions as compared to standard care without SpHb monitoring.[1]

SpHb monitoring is not intended to be used as the sole basis for making diagnosis or treatment decisions. Clinical decisions regarding red blood cell transfusions should be based on the clinician's judgment considering among other factors: patient condition, continuous SpHb monitoring, and laboratory diagnostic tests using blood samples.

www.masimo.co.uk/sphb

For professional use. See instructions for use for full prescribing information, including indications, contraindications, warnings, and precautions.

 [1] Ehrenfeld et al. *J Blood Disorders Transf* 2014. 5:9.

Masimo

PLCO-002997/PLMM-11098A-0719
PLLT-10028F