

Guidelines

Difficult Airway Society Guidelines for the management of tracheal extubation

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Summary

Tracheal extubation is a high-risk phase of anaesthesia. The majority of problems that occur during extubation and emergence are of a minor nature, but a small and significant number may result in injury or death. The need for a strategy incorporating extubation is mentioned in several international airway management guidelines, but the subject is not discussed in detail, and the emphasis has been on extubation of the patient with a difficult airway. The Difficult Airway Society has developed guidelines for the safe management of tracheal extubation in adult peri-operative practice. The guidelines discuss the problems arising during extubation and recovery and promote a strategic, stepwise approach to extubation. They emphasise the importance of planning and preparation, and include practical techniques for use in clinical practice and recommendations for post-extubation care.

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What other guideline statements are available on this topic?

The need for a strategy incorporating extubation is mentioned in several international airway management guidelines: the Canadian Airway Focus Group's 1998 recommendations for the management of the unanticipated difficult airway; the 2003 American Society of Anesthesiologists (ASA) difficult airway guidelines; the Società Italiana Anaesthesia Analgesia Rianimazione Terapia Intensiva (SIAARTI) recommendations for airway control and difficult airway management 2005. The Difficult Airway Society (DAS) difficult intubation guidelines of 2004 mention the need for a pre-formulated extubation plan, but no details are given.

Why was this guideline developed?

Complications are common at extubation and during recovery and may result in significant morbidity and mortality. Although extubation is addressed in some airway management guidelines, it has not received the same attention as intubation.

How does this statement differ from existing guidelines?

These guidelines recommend that an extubation strategy should be developed before the start of anaesthesia. A stepwise approach is used to aid risk stratification, the practical management of routine and at-risk situations, and to highlight the importance of continued postextubation care. Flowcharts have been produced to summarise this philosophy. The guidelines are applicable to adult peri-operative practice; they do not address paediatric or critical care patients.

Why does this statement differ from existing guidelines?

These guidelines explore the pathophysiology of problems arising during extubation and emergence. They address the importance of planning extubation to avoid difficulties. They provide a structured framework around which extubation can be managed and taught and offer practical strategies for use in clinical practice.

Tracheal extubation is a critical step during emergence from general anaesthesia. It is not simply a reversal of the process of intubation because conditions are often less favourable than at the start of anaesthesia. At extubation, there is a transition from a controlled to an uncontrolled situation. Anatomical and physiological changes, compounded by time pressures and other constraints, contribute to a situation that can be more challenging for the anaesthetist than tracheal intubation.

Although the majority of problems following extubation are of a minor nature, a small but significant number have serious consequences, including hypoxic brain injury and death [1-6].

Data from the UK suggest that respiratory complications are common at extubation and during recovery [7, 8]. In the fourth National Audit Project (NAP4) of the Royal College of Anaesthetists and the DAS, major airway complications occurred during emergence or in recovery in approximately one third of the reported cases relating to anaesthesia [9].

Closed-claims data from the US have demonstrated morbidity and mortality associated with extubation [10]. Following the publication of the ASA guidelines for management of the difficult airway, there was a statistically significant reduction in airway claims arising from injury at induction of anaesthesia. However, claims arising from injury intra-operatively, at extubation and during recovery did not change. Death or brain injury was more common in claims associated with extubation and recovery than those occurring at the time of induction of anaesthesia. Problems at extubation were more common in patients who were obese and in those with obstructive sleep apnoea.

Despite evidence of high complication risks, tracheal extubation and emergence from anaesthesia have generated less interest than induction and intubation. Many international guidelines for the management of difficult intubation are available, but few discuss extubation in any detail [11-16]. In the UK, the Royal College of Anaesthetists' training syllabus contains very little information on extubation [17]. The DAS difficult intubation guidelines have been widely adopted by UK anaesthetists since their publication in 2004, and although extubation is mentioned, it is not addressed in any detail [18]. For these reasons, DAS decided to

produce guidelines for the management of tracheal extubation in adult peri-operative practice.

By way of a disclaimer, it is not intended that these guidelines should constitute a minimum standard of practice, nor are they to be regarded as a substitute for good clinical judgement.

Methods

The need for extubation guidelines was established at the DAS Annual General Meeting in 2007, and a working group was convened.

Identification of evidence

A preliminary search of international guidelines and published literature was performed. Anaesthetic airway management guidelines published by nationally recognised scientific societies were used to determine the standards required to formulate recommendations [11-15, 18, 19].

A structured literature search of available scientific publications from 1970 to 2008 was carried out using databases (Medline, Embase, PubMed, National Guidelines Clearinghouse), search engines (Google Scholar and Scirus) and officially recognised websites (DAS (<http://www.das.uk.com>), Society of Airway Management (<http://samhq.com>), ASA (<http://www.asahq.org>), European Society of Anaesthesiologists (<http://www.euroanesthesia.org>)). English language and English abstract publications were searched using keywords and filters. The most commonly used words and phrases included 'tracheal extubation', 'extubation', 'complications', 'difficult airway', 'difficult extubation', 'general anaesthesia', 'laryngospasm', 'post-obstructive pulmonary oedema', 'cardiovascular', 'airway exchange catheter', 'AEC', 'remifentanyl', 'laryngeal mask', 'supraglottic airway', 'subglottic', 'tracheostomy', 'steroids', 'recovery'. The search was repeated every six months until June 2011. Initially, 6215 abstracts were retrieved, of which 327 were considered relevant. These were examined for data overlap and original research. These findings were extended by cross-referencing the data and hand-searching. As we did not find any large randomised controlled trials in extubation practice, expert opinion in the form of editorials, book chapters and comments was taken into consideration.

Classification of evidence

All scientific publications were reviewed according to the Oxford Centre for Evidence Based Medicine criteria [20]. The literature was grouped according to both levels of evidence and core topic (primary physiological research, complications and management, airway techniques). The aim of this process was to obtain studies with high levels of evidence to support any recommendations made.

The lack of any large, prospective, randomised controlled trials or meta-analyses in extubation practice and the difficulty in making recommendations based on high grades of evidence was discussed at DAS annual meetings in 2008 and 2009. With DAS Committee approval and general agreement of members, it was decided to produce guidelines that would be simple, pragmatic and useful in day-to-day practice. A draft version of the guidelines was circulated to interested members of DAS and acknowledged international experts for comment. Before submission for publication, the algorithms were displayed on the DAS website and all members were invited to comment.

Problems at extubation: why is extubation hazardous?

The purpose of tracheal intubation is to provide airway patency, ensure airway protection, aid ventilation of the lungs and improve surgical access. In most patients, removal of the tracheal tube – the process of extubation – is uneventful. However, in a minority of cases, anatomical and/or physiological compromise can result in morbidity and mortality. These problems arise more frequently in patients who fall into the ‘at-risk’ group (see below). The problems related to extubation are not only technical and may be compounded by human factors [2–4, 21].

Problems related to airway reflexes

The return of airway reflexes depends on many factors, and may be delayed for some hours after removal of the tracheal tube. In practice, exaggerated, reduced (obtunded) and dysfunctional reflexes may all cause problems [22].

Exaggerated laryngeal reflexes

Breath holding, coughing and bucking (a forceful and protracted cough that mimics a Valsalva manoeuvre) are

physiological responses to airway stimulation and are associated with increases in arterial blood pressure, venous pressure and heart rate.

Laryngospasm is a protective exaggeration of the normal glottic closure reflex, and is produced by stimulation of the superior laryngeal nerve [23–27]. Laryngospasm is often triggered by the presence of blood, secretions or surgical debris, particularly in a light plane of anaesthesia. Nasal, buccal, pharyngeal or laryngeal irritation, upper abdominal stimulation or manipulation and smell have all been implicated in the aetiology of laryngospasm. Clinical experience suggests that intravenous anaesthesia using a propofol-based technique is associated with a lower incidence of complications related to exaggerated airway reflexes, and there is some evidence to support this [28–31]. Typically, laryngospasm causes signs of upper airway obstruction (including stridor) that can precede complete airway obstruction and requires an immediate response (Appendix 1A). If not relieved promptly, laryngospasm may result in post-obstructive pulmonary oedema (also known as negative pressure pulmonary oedema) and hypoxic cardiac arrest (Appendix 2B) [32–36]. The equivalent response in the lower airway is bronchospasm.

Reduced airway reflexes

Upper airway reflexes maintain tone and upper airway patency; laryngeal reflexes protect the lower airway.

Many factors can contribute to a reduction in pharyngeal tone, causing collapse and airway obstruction [37, 38]. This is a particular problem in obese patients and in those with obstructive sleep apnoea (OSA), who are more sensitive to the effects of opioids and residual anaesthesia [39, 40]. Late airway obstruction following opioid administration is a recognised problem in OSA patients [41]. Residual neuromuscular blockade has been shown to increase the incidence of postoperative respiratory complications. Train-of-four ratios of 0.7–0.9 are associated with impaired pharyngeal function, airway obstruction, increased risk of aspiration and attenuation of the hypoxic ventilatory response [42–44].

Reduced laryngotracheal reflexes increase the risk of aspiration and airway soiling. Partial or complete airway obstruction with forceful inspiratory effort generates a significant negative intrathoracic pressure, which opens the oesophagus increasing the risk of regurgitation [45].

Forceful positive pressure ventilation via a facemask or supraglottic airway device, for example during difficult bag/mask ventilation, may overcome lower oesophageal sphincter tone and distend the stomach.

The presence of blood in the airway is significant if airway reflexes are obtunded, because the aspiration of blood clots can cause complete airway obstruction [46].

Protective laryngeal reflexes are impaired after tracheal extubation, and may be compromised following airway management with a supraglottic airway device [47–49].

Dysfunctional laryngeal reflexes

Paradoxical vocal cord motion describes a rare condition in which vocal cord adduction occurs on inspiration, and can cause stridor following extubation. It is more common in young females and in those with emotional stress. The condition is often misdiagnosed and treated as laryngospasm or bronchospasm. The diagnosis can only be made by direct observation of the vocal cords, and responds to treatment with anxiolytic, sedative or opioid agents [50–53].

Depletion of oxygen stores at extubation

Following extubation, the aim is to provide an uninterrupted supply of oxygen to the patient's lungs. Various factors that contribute to rapid depletion of oxygen stores and a reduction in arterial oxygen saturation are summarised in Table 1.

Airway injury

Injury to the airway may be the result of direct trauma following surgical or anaesthetic intervention, or it may be indirect due to subsequent bleeding, swelling or oedema.

Any surgery or insult in or around the airway can cause problems following extubation. Thyroid surgery, laryngoscopy, panendoscopy, and maxillofacial, cervical spine, carotid and other head/neck procedures can cause direct airway compromise due to haematoma, oedema, altered lymphatic drainage, vocal cord paralysis and tracheomalacia [54, 55]. Patient position (prone or prolonged Trendelenburg positions), duration of surgery, fluid overload and anaphylaxis may contribute to airway oedema.

Table 1 Factors contributing to reduction in arterial oxygen saturation and depletion of oxygen stores at extubation.

Pathophysiological	Reduced functional residual capacity Hypoventilation Diffusion hypoxia Atelectasis Ventilation/perfusion mismatch Problems related to airway reflexes Shivering Cardiovascular instability Neurological dysfunction Metabolic derangement Electrolyte disturbances Airway injury
Pharmacological	Neuromuscular blocking drugs Opioids Residual anaesthetic agents
Human & other factors	Inadequate equipment Inadequate skilled assistance Patient position Access to airway e.g. dressings/gastric tubes/rigid fixators Interruption of oxygen supply during patient transfer Communication difficulties (e.g. language, mental capacity) Removal of oxygen by agitated or uncooperative patient

Anaesthetic airway injury may result from laryngoscopy, or insertion and presence of a tracheal tube or airway adjuncts. Periglottic trauma may result from transoesophageal echocardiography probes and nasogastric tubes, from the use of inappropriately large tube sizes and excessive cuff pressure or from incorrectly positioned tracheal tubes (e.g. with a cuff inflated within the larynx). Problems resulting from airway injury often do not become apparent until after tracheal extubation; direct problems include crico-arytenoid joint dysfunction and vocal cord palsy, and indirect problems may result from pressure effects secondary to haematoma, oedema or mediastinitis [56].

The ASA closed-claims analysis of airway injury during anaesthesia showed that 33% of injuries occurred at the larynx, 19% at the pharynx, 18% at the oesophagus, 15% at the trachea, 10% at the temporomandibular joint and 5% at the nose. Of the laryngeal injuries leading to claims, vocal cord paralysis was the most common (34%) followed by granuloma (17%), arytenoid dislocation (8%) and haematoma (3%). Most (85%) of the laryngeal injuries were associated with

short-term tracheal intubation and 80% followed routine (not difficult) tracheal intubation [57]. In adults, the glottis is the narrowest part of the airway, and the posterior glottis supports the tracheal tube. Movement of oversized or poorly positioned tracheal tubes, or overinflated cuffs, on the posterior glottis and arytenoids cartilages can lead to oedema and compromised airflow [58]. Supraglottic swelling and oedema can cause posterior displacement of the epiglottis and (typically) inspiratory obstruction. Glottic, subglottic and tracheal oedema can cause life-threatening airway compromise.

Physiological compromise in other systems

The process of extubation causes exaggerated reflexes in other physiological systems resulting in hypertension, tachycardia (with associated myocardial ischaemia), raised venous pressures and increase in intra-ocular and intracerebral pressures [59–63].

Human factors

The environment at extubation is not as favourable as at intubation. Equipment, monitoring and assistance may be inadequate. Patient factors contributing to extubation problems may be compounded by distraction, time pressure, operator fatigue, lack of equipment or skilled assistance and poor communication [64–66].

Managing extubation

There is a lack of compelling evidence to support a 'one size fits all' extubation strategy for every patient. There is, however, a general agreement that good preparation is key to successful airway management and that an extubation strategy should be in place for every patient [10, 18, 67, 68].

General principles

Extubation is an elective process, and it is important to plan and execute it well. The goal is to ensure uninterrupted oxygen delivery to the patient's lungs, avoid airway stimulation, and have a back-up plan, that would permit ventilation and re-intubation with minimum difficulty and delay should extubation fail. Since the introduction of the DAS unanticipated difficult intubation guidelines, the concept of a stepwise approach has been widely accepted. This approach has

been used to aid decision making and safe management of extubation.

The DAS extubation guidelines (Figs. 1–3)

The guidelines describe the following four steps:

Step 1: plan extubation.

Step 2: prepare for extubation.

Step 3: perform extubation.

Step 4: post-extubation care: recovery and follow-up.

Step 1: plan extubation

An outline extubation plan should be in place before induction of anaesthesia and reviewed throughout and immediately before performing extubation. Planning involves an assessment of the airway and general risk factors. The following questions may aid in the decision making process [69], answers to which will help determine whether extubation is 'low-risk' or 'at-risk' [67]:

1 Are there airway risk factors?

- was the airway normal/uncomplicated at induction?
- has the airway changed?

2 Are there general risk factors?

Low-risk extubation. This is a routine or uncomplicated extubation. The airway was normal/uncomplicated at induction and remains unchanged at the end of surgery, and no general risk factors are present.

'At-risk' extubation. This is an extubation 'at risk' of potential complications. Airway risk factors are present:

- 1 ***Pre-existing airway difficulties.*** Airway access was difficult at induction (anticipated or unanticipated) and may have worsened intra-operatively. This group includes patients with obesity and OSA, and those at risk of aspiration of gastric contents;
- 2 ***Peri-operative airway deterioration.*** The airway was normal at induction, but may have become difficult to manage, for example, due to distorted anatomy, haemorrhage, haematoma or oedema resulting from surgery, trauma or non-surgical factors;
- 3 ***Restricted airway access.*** Airway access was straightforward at induction, but is limited at the end of surgery, for example, where the airway is shared, or head/neck movements restricted (halo fixation, mandibular wiring, surgical implants, cervical spine fixation).

General risk factors may also be present; these may complicate or even preclude extubation, and include impaired respiratory function, cardiovascular instability, neurological/neuromuscular impairment, hypo/hyperthermia, and abnormalities of clotting, acid-base balance or electrolyte levels.

Smooth emergence from anaesthesia is desirable for the success of some surgical procedures. For example, coughing and straining can cause raised venous pressure resulting in haematoma formation, airway compression and suture disruption. Raised intra-ocular and intracranial pressures can compromise surgical outcomes. Cardiovascular changes may put the patient with severe ischaemic heart disease at risk [62, 70].

Step 2: prepare for extubation

Preparation is aimed at the final optimisation of airway, general and logistical factors to ensure the best possible conditions for success extubation. Together with planning (step 1), preparation (step 2) enables the risk stratification of extubation into 'low-risk' and 'at-risk' categories, and should always precede extubation (step 3).

Final evaluation and optimisation of airway factors. The airway should be reassessed at the end of surgery and before extubation. This review should be used to finalise the extubation plan and to determine the most appropriate rescue plan for re-intubation should extubation fail.

Assessment should follow a logical sequence:

- 1 Airway. It is essential to consider whether bag-mask ventilation would be achievable. Oedema, bleeding, blood clots, trauma, foreign bodies and airway distortion can be assessed by direct or indirect laryngoscopy. It is important to remember both that the presence of a tracheal tube may give a falsely optimistic view of the larynx at direct laryngoscopy, and that oedema may progress very rapidly;
- 2 Larynx. A cuff-leak test may be used to assess subglottic calibre. Clinically, the presence of a large audible leak when the tracheal tube cuff is deflated is reassuring; the absence of a leak around an appropriately sized tube generally precludes safe extubation. If the clinical conditions suggest airway oedema, caution should be exercised even if there is a cuff leak. Spirometry allows quantitative assessment of a cuff leak and is sensitive, but lacks specificity [71-76].

- 3 Lower airway. It is important to consider factors in the lower airway that may contraindicate extubation, such as lower airway trauma, oedema, infection and secretions. Chest radiography may be necessary to exclude bronchial intubation, pneumothorax, surgical emphysema or other pulmonary pathology, if intubation was difficult or oxygenation suboptimal during surgery.

Gastric distension splints the diaphragm and restricts breathing. Gastric decompression with an oro/nasogastric tube is advisable if high-pressure facemask/supraglottic airway ventilation has been necessary.

If the airway rescue plan involves subglottic access then ability to access the neck should be confirmed.

Final evaluation and optimisation of general factors. Neuromuscular block should be fully reversed to maximise the likelihood of adequate ventilation, and restore protective airway reflexes and the ability to clear upper airway secretions. The use of a peripheral nerve stimulator to ensure a train-of-four ratio of 0.9 or above is recommended and has been shown to reduce the incidence of postoperative airway complications. An accelerometer is more accurate than visual assessment for train-of-four response [42, 77]. Sugammadex provides more reliable antagonism of rocuronium- (and to a lesser extent vecuronium-) induced neuromuscular blockade than neostigmine. Cardiovascular instability should be corrected and adequate fluid balance assured. The patient's body temperature, acid-base balance, electrolyte and coagulation status should be optimised. Adequate analgesia should be provided.

Final evaluation and optimisation of logistical factors. Extubation is an elective process, which should be carried out in a controlled manner with the same standards of monitoring, equipment and assistance that are available at induction. Tracheal extubation can take as long to perform safely as tracheal intubation, and this should be considered when organising list schedules, or sending for the next patient. Communication is essential, and the anaesthetist, surgeon and theatre team all play an important role. Additional resources may be required for the 'at risk' patient.

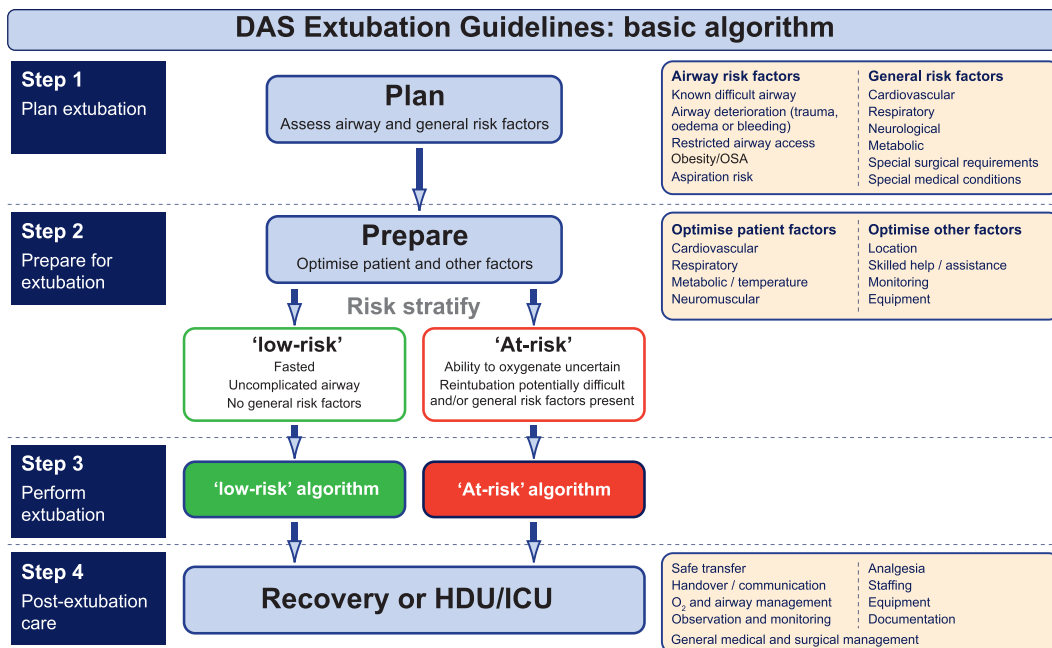


Figure 1 DAS extubation guidelines: basic algorithm.

Step 3: perform extubation

Step 3 involves the actual performance of extubation.

General considerations. Any extubation technique used should ensure minimum interruption in oxygen delivery to the patient’s lungs. The following general considerations are relevant to extubation for both the ‘low-risk’ and the ‘at-risk’ groups:

Building oxygen stores (pre-oxygenation): the peri-operative anatomical and physiological changes described above compromise gas exchange, and make pre-oxygenation before extubation vital. As for induction of anaesthesia, the aim of pre-oxygenation before extubation is to maximise pulmonary oxygen stores by raising the F_EO₂ above 0.9, or as close to the F_IO₂ as possible [78]. Although studies have shown that an F_IO₂ of 1.0 increases atelectasis, the clinical significance of this has yet to be determined [79, 80]. At extubation, the priority is to maximise oxygen stores to continue oxygen uptake during apnoea, and therefore pre-oxygenation with a F_IO₂ of 1.0 is recommended [81–85].

Patient position: there is no evidence to support a universal patient position for extubation. There is an increasing trend towards extubating in a head-up (reverse Trendelenburg) or semi-recumbent position. The head-up tilt is especially useful in the obese

population as it confers a mechanical advantage to respiration and provides more familiar conditions in which to monitor and manage the airway. A left-lateral, head-down position has traditionally been used for the non-fasted patient [77, 86].

Suction: the soft tissues of the oropharynx are at risk of trauma if suction is not applied under direct vision [87, 88], ideally using a laryngoscope, particularly if there are concerns about oropharyngeal soiling from secretions, blood or surgical debris. Laryngoscopy should be carried out with the patient in an adequately deep plane of anaesthesia, but may need to be repeated. Special vigilance is necessary if there is blood in the airway, as NAP4 highlighted the danger of the ‘coroner’s clot’, where aspiration of blood can lead to airway obstruction and death [89]. Suction of the lower airway using endobronchial catheters, together with aspiration of gastric tubes, may also be necessary.

Alveolar recruitment manoeuvres: patients undergoing anaesthesia develop atelectasis. Alveolar recruitment manoeuvres, such as sustained positive end-expiratory pressure (PEEP) and vital capacity breaths, may temporarily reverse atelectasis, but have not been shown to provide any benefit in the post-operative period [81, 90]. Simultaneous deflation of the tracheal tube cuff and removal of the tube at the peak of

a sustained inflation generates a passive exhalation, and may be sensibly employed to expel secretions and possibly reduce the incidence of laryngospasm and breathholding.

Bite block: a bite block prevents occlusion of the tracheal tube should the patient bite down during emergence from anaesthesia [91–93]. Forced inspiratory efforts against an obstructed airway can rapidly lead to pulmonary oedema (see Appendix 2B) [94]. Should biting occur, deflating the cuff of the tube or laryngeal mask airway (LMA) may prevent post-obstructive pulmonary oedema, as significant negative pressure cannot be generated if air can flow around the device. Various devices have been used as bite blocks, including the Guedel airway. When rolled gauze is used, it is important that it is tied or taped to the tracheal tube to prevent displacement or accidental airway obstruction.

Avoidance of the sequelae of airway stimulation: traditionally, extubation has been performed when the patient is either fully 'awake' or deeply anaesthetised.

Awake extubation is generally safer as the return of airway tone, reflexes and respiratory drive allows the patient to maintain their own airway.

Deep extubation reduces the incidence of coughing, bucking and the haemodynamic effects of tracheal tube movement, but these advantages are offset by an increased incidence of upper airway obstruction [95–97]. This is an advanced technique, which should be reserved for patients in whom airway management would be easy and who are not at increased risk of aspiration.

It is possible to reduce the risk of airway obstruction by exchanging the tracheal tube for a LMA before emergence (Bailey manoeuvre; see below) [98].

Opioids such as alfentanil, fentanyl and morphine have been used to suppress any cough reflex. Currently, the ultrashort-acting opioid remifentanyl, administered by infusion, is the drug of choice for this technique, but requires careful administration (see below). The benefits of cough suppression must be weighed against the increased risks of sedation and respiratory depression. Lidocaine has been used to reduce coughing; it may be administered topically at intubation, into the cuff of the tracheal tube or intravenously before extubation, with some benefit [77].

Other pharmacological agents have been used to attenuate the cardiovascular and respiratory changes associated with extubation, including opioids, calcium channel antagonists, magnesium, lidocaine, clonidine, ketamine and beta blockers [28, 99–103]. Doxapram has been used to prevent and/or treat laryngospasm, although it is associated with cardiovascular stimulation and robust evidence to support its use for this indication is lacking [104]. The use of steroids to reduce inflammatory airway oedema is described below [105–107].

The performance of 'low-risk' (routine) extubation. Whilst no extubation is without risk, routine extubation is characterised by the expectation that reintubation could be managed without difficulty, if required.

Stepwise approaches to awake and deep 'low-risk' extubations are given in Tables 2 and 3, respectively.

The performance of 'at-risk' extubation. An 'at-risk' extubation is one in which the risk stratification (steps 1 and 2 above) has identified general and/or airway risk factors that suggest that a patient may not be able to maintain his/her own airway after removal of the tracheal tube. 'At-risk' extubation is characterised by the concern that airway management may not be straightforward should reintubation be required.

An example of an 'at-risk' extubation might involve the patient having emergency surgery to repair a leaking aortic aneurysm for whom general factors such as a full stomach, unstable cardiovascular physiology, acid-base derangement or temperature control can make extubation more challenging.

An example of 'at-risk' extubation due to airway factors might involve the patient undergoing head and neck surgery after awake fiberoptic intubation before induction of general anaesthesia, because of previous head and neck radiotherapy.

Step 1 would stratify both these patients into the 'at-risk' extubation group. Step 2 would enable stabilisation of general factors and optimisation of logistical factors e.g. communication with the intensive care unit, assembling equipment, getting help.

The key decision to be made is whether it is safer to extubate, or preferable for the patient's trachea to remain intubated. If it is considered safe to extubate, then an

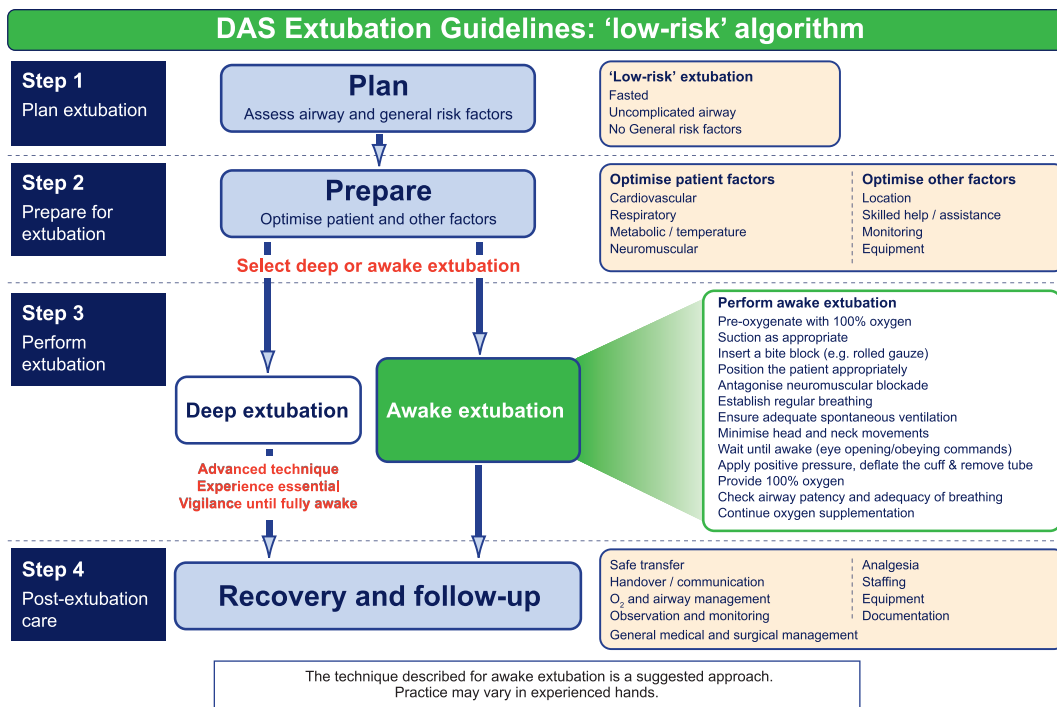


Figure 2 DAS extubation guidelines: 'low-risk' algorithm.

awake extubation or one the advanced techniques described below will overcome most of the challenges in the 'at-risk' patient. A broad range of equipment and advanced techniques are available, but no single technique covers all clinical scenarios. None of these techniques is without risk; training and experience in their use are vital before they are employed in a difficult airway situation. If it is considered unsafe to extubate, the options are to postpone extubation or perform a tracheostomy.

Awake extubation: the technique of awake extubation for the 'at-risk' patient is the same as that described above for the low-risk group, and is suitable for most patients in the 'at-risk' group (for example, those at risk of aspiration, the obese, and many patients with a difficult airway). However, in some situations, one or more of the following advanced techniques may be beneficial:

Laryngeal mask exchange (Bailey manoeuvre): this involves replacement of a tracheal tube with a LMA to maintain a patent, unstimulated airway with stable physiological observations and protection of the airway from soiling secondary to blood and secretions in the mouth. The emergence profile of this technique is superior to either awake or deep extubation [108-111], and is useful in cases where there is a risk of disruption of the surgical repair due to the cardiovascular stimulation

resulting from the presence of a tracheal tube. It may also benefit smokers, asthmatics and other patients with irritable airways. It is inappropriate in patients in whom re-intubation would be difficult or if there is a risk of regurgitation. The technique was originally described using the Classic LMA [98, 112]. Data for use of other supraglottic airway devices are lacking. The technique

Table 2 Sequence for 'low-risk' extubation in an awake patient.

- 1 Deliver 100% oxygen through the breathing system
- 2 Remove oropharyngeal secretions using a suction device, ideally under direct vision
- 3 Insert a bite block to prevent occlusion of the tube
- 4 Position the patient appropriately
- 5 Antagonise residual neuromuscular blockade
- 6 Establish regular breathing and an adequate spontaneous minute ventilation
- 7 Allow emergence to an awake state of eye-opening and obeying commands
- 8 Minimise head and neck movements
- 9 Apply positive pressure, deflate the cuff and remove the tube while the lung is near vital capacity
- 10 Provide 100% oxygen with an anaesthetic breathing system and confirm airway patency and adequacy of breathing
- 11 Continue delivering oxygen by mask until recovery is complete

Table 3 Sequence for 'low-risk', deep extubation. Deep extubation is a technique that should be reserved for spontaneously breathing patients with uncomplicated airways and only performed by clinicians familiar with the technique.

- 1 Ensure that there is no further surgical stimulation
- 2 Balance adequate analgesia against inhibition of respiratory drive
- 3 Deliver 100% oxygen through the breathing system
- 4 Ensure adequate depth of anaesthesia with volatile agent or TIVA as appropriate
- 5 Position the patient appropriately
- 6 Remove oropharyngeal secretions using a suction device, ideally under direct vision
- 7 Deflate the tracheal tube cuff. Airway responses such as cough, gag or a change in breathing pattern indicate an inadequate depth and the need to deepen anaesthesia
- 8 Apply positive pressure via the breathing circuit and remove the tracheal tube
- 9 Reconfirm airway patency and adequacy of breathing
- 10 Maintain airway patency with simple airway manoeuvres or oro-/nasopharyngeal airway until the patient is fully awake
- 11 Continue delivering oxygen by mask until recovery is complete
- 12 Anaesthetic supervision is needed until the patient is awake and maintaining their own airway

requires practice and meticulous attention to detail; adequate depth of anaesthesia is critical to avoid laryngospasm (Table 4).

This method favours correct positioning of the LMA as the tracheal tube splints the epiglottis as it is inserted, preventing downfolding of the epiglottis. Similar techniques to the Bailey manoeuvre include:

- 1 Removal of the tracheal tube before LMA insertion, following laryngoscopy and pharyngeal suction;
- 2 Insertion of a flexible fiberoptic bronchoscope through the stem of the LMA, to confirm its correct position, and to observe vocal cord motion. This technique is useful for patients who have had thyroid/parathyroid surgery and other situations in which airway integrity may have been impaired;
- 3 Laryngeal mask airway exchange for a nasotracheal tube, using one of two methods: the LMA may be inserted from the side of the nasotracheal tube so that the former slides behind the latter; or the nasotracheal tube can be removed before inserting the LMA.

Remifentanil extubation technique: the presence of a tracheal tube may trigger coughing, agitation and haemodynamic disturbances during emergence from

Table 4 Sequence for LMA exchange in 'at-risk' extubation.

- 1 Administer 100% oxygen
- 2 Avoid airway stimulation: either deep anaesthesia or neuromuscular blockade is essential
- 3 Perform laryngoscopy and suction under direct vision
- 4 Insert deflated LMA behind the tracheal tube
- 5 Ensure LMA placement with the tip in its correct position
- 6 Inflate cuff of LMA
- 7 Deflate tracheal tube cuff and remove tube whilst maintaining positive pressure
- 8 Continue oxygen delivery via LMA
- 9 Insert a bite block
- 10 Sit the patient upright
- 11 Allow undisturbed emergence from anaesthesia

anaesthesia. In certain groups of patients (for example, neurosurgical, maxillofacial, plastics and those with significant cardiac or cerebrovascular disease), these responses are undesirable. Although possible, both awake and deep extubation are far from ideal in these situations. The cough suppressant effects of opioid drugs and their ability to attenuate the cardiovascular changes with extubation have been known for many years [113, 114]. Infusion of the ultrashort-acting opioid remifentanil attenuates these undesirable responses and may be used to provide the beneficial combination of a tube-tolerant patient who is fully awake and obeys commands.

Remifentanil infusions have been extensively described as a method of providing conscious sedation for awake fiberoptic intubation in the spontaneously breathing patient [115-119] and evidence is emerging to support a similar strategy during emergence and extubation [120-125]. Several factors influence the dose of remifentanil necessary to prevent coughing at extubation, and relate to patient characteristics, surgical procedure and the anaesthetic technique. A remifentanil infusion can be used in two ways: infusion may be continued after intra-operative use; or it can be administered specifically for extubation. The success of these approaches lies in removing the hypnotic component of anaesthesia (inhalational agent or propofol) well in advance of extubation, allowing appropriate titration of remifentanil. A broad range of doses have been described in the literature, but generally titration aims to avoid either coughing (too low a dose) or delayed emergence and apnoea (too high a dose) (Table 5).

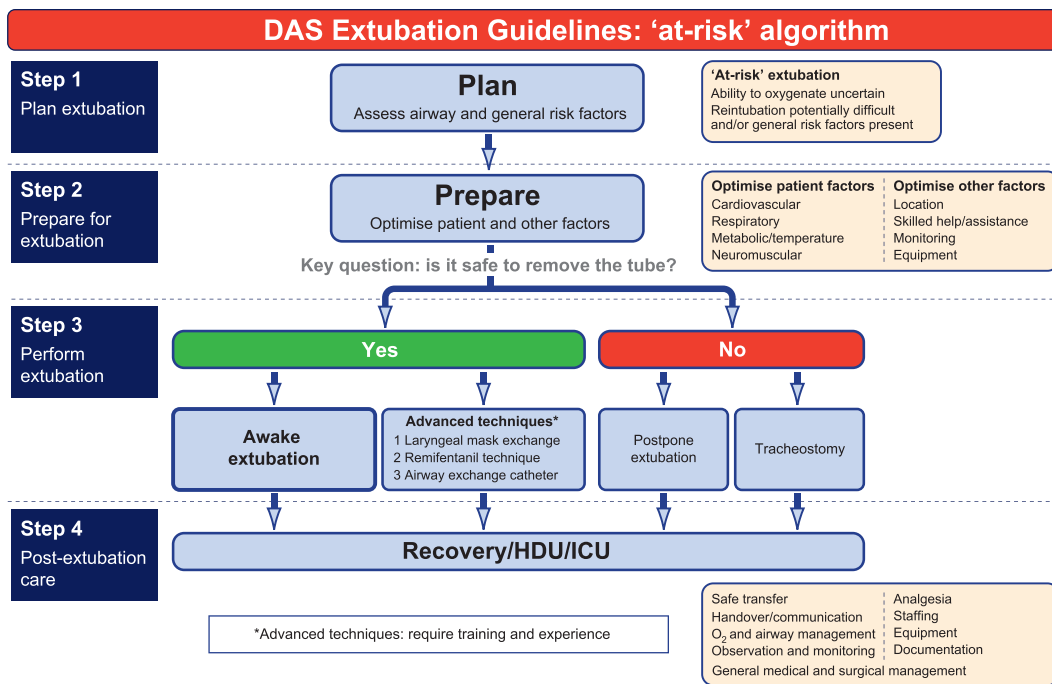


Figure 3 DAS extubation guidelines: 'at-risk' algorithm.

Airway exchange catheter-assisted extubation: patients for whom reintubation is likely to be difficult may benefit from continuous airway access, which can be achieved with an airway exchange catheter (AEC) [127, 128]. This device is inserted into the trachea through the tracheal tube before extubation. The concept of managing extubation with specially designed long, hollow tracheal ventilation catheters in patients with difficult airways was developed by Bedger and Chang and later used by Cooper in a series of 202 patients [129-131]. Other similar devices have been described, but the only device that is commercially available in the UK for this purpose is the Cook Airway Exchange Catheters (William Cook Europe, Bjaeverskov, Denmark). The use of suction catheters, nasogastric tubes, bougies and the Aintree Intubation Catheter (William Cook Europe) have been described, but these have limitations [132].

Airway exchange catheters are long, thin hollow tubes made from semi-rigid thermostable polyurethane. They are blunt-ended, have distal terminal and side holes, are radiopaque and have length markings on the exterior surface. They are supplied with removable 15-mm connectors that are compatible with anaesthetic circuits and/or Luer lock connectors for use with high-

pressure source (jet) ventilation or oxygen tubing. They are available in a range of sizes, the most appropriate for extubation being the 83-cm long 11- and 14-FG catheters; these have internal diameters of 2.3 and 3 mm respectively, with external diameters of 3.7 and 4.7 mm that are compatible with tracheal tubes of internal diameters more than 4 and 5 mm, respectively.

Airway exchange catheters can be used as a guide over which a tracheal tube can be passed should reintubation become necessary, and can be used to oxygenate the patient's lungs. They have a high success rate when used as a guide for reintubation. Most of the morbidity attributed to their use is associated with oxygenation and inappropriate positioning. Meticulous care must be taken to ensure that the distal tip is positioned in the mid trachea at all times. Oxygen insufflation and high-pressure source (jet) ventilation should only be undertaken with extreme caution as barotrauma and death have been reported [133-136]. Anaesthetists should be familiar with these devices: training, practice and rehearsal can be achieved using manikin-based scenarios.

A prospective study of 354 patients with difficult airways over a nine-year period confirmed the safety and efficacy of AECs [137]. There was a high degree of

Table 5 Sequence for use of a remifentanyl infusion for 'at-risk' extubation.

- 1 Consider postoperative analgesia. If appropriate, administer intravenous morphine before the end of the operation [126]
- 2 Before the end of the procedure, set the remifentanyl infusion at the desired rate
- 3 Antagonise neuromuscular blockade at an appropriate phase of surgery and emergence
- 4 Discontinue anaesthetic agent (inhalational agent or propofol)
- 5 If using inhalational agent, use high-flow oxygen-enriched gas mixture to aid full elimination and monitor its end tidal concentration
- 6 Continue ventilation
- 7 Laryngoscopy and suction should be performed under direct vision if appropriate
- 8 Sit the patient upright
- 9 Do not rush, do not stimulate, wait until the patient opens their eyes to command
- 10 Discontinue positive pressure ventilation
- 11 If spontaneous respiration is adequate, remove the tracheal tube and stop the infusion
- 12 If spontaneous respiration is inadequate, encourage the patient to take deep breaths and reduce the infusion rate
- 13 When respiration is adequate, remove the tracheal tube and discontinue the remifentanyl infusion, taking care to flush residual drug from the cannula
- 14 After extubation, there is a risk of respiratory depression and it is essential that the patient is closely monitored until fully recovered
- 15 Remember that remifentanyl has no long-term analgesic effects
- 16 Remember that remifentanyl can be antagonised by naloxone

successful first attempts at reintubation. Complications, including low oxygen saturation, bradycardia, hypotension, oesophageal intubation and use of accessory airway adjuncts were less common when reintubation was performed using an AEC. Other studies in patients with difficult airways have also reported successful outcomes [128, 138]. Observation of the larynx, either by direct or videolaryngoscopy, increases the success of reintubation using an AEC and reduces complications [139]. Attention to detail and due care must be exercised in the use of an AEC, as the complications of their use may be severe.

Four techniques involving AEC-assisted extubation require consideration:

- 1 Inserting the AEC before extubation (Table 6).
- 2 Respiratory deterioration: maintaining oxygenation. Identify the cause of the respiratory deterioration and

Table 6 Sequence for use of an airway exchange catheter for 'at-risk' extubation.

- 1 Decide how far to insert the AEC. It is essential that the distal tip remains above the carina. If there is any uncertainty about the position of the tracheal tube tip, its position relative to the carina should be checked with a fiberoptic bronchoscope before AEC insertion. An AEC should never be inserted beyond 25 cm in an adult patient
- 2 When the patient is ready for extubation, insert the lubricated AEC through the tracheal tube to the predetermined depth. Never advance an AEC against resistance
- 3 Employ pharyngeal suction before removal of the tracheal tube
- 4 Remove the tracheal tube over the AEC, while maintaining the AEC position (do not advance the AEC)
- 5 Secure AEC to the cheek or forehead with tape
- 6 Record the depth at the teeth/lips/nose in the patient's notes
- 7 Check that there is a leak around AEC using an anaesthetic circuit
- 8 Clearly label the AEC to prevent confusion with a nasogastric tube
- 9 The patient should be nursed in a high dependency or critical care unit
- 10 Supplemental oxygen can be given via a facemask, nasal cannula or CPAP mask
- 11 The patient should remain nil by mouth until the AEC is removed
- 12 If the presence of the AEC causes coughing, check that the tip is above the carina and inject lidocaine via the AEC
- 13 Most patients remain able to cough and vocalise
- 14 Remove the AEC when the airway is no longer at risk. They can be tolerated for up to 72 hours [137]

institute appropriate measures. If the deterioration is associated with upper airway obstruction, high-flow oxygen should be given by facemask only (not via the AEC), standard airway manoeuvres or adjuncts should be used, mask-delivered continuous positive airway pressure (CPAP) can be applied if the AEC is moved to the corner of the mouth to provide an adequate facemask seal, and adrenaline should be nebulised via the facemask. Helium-oxygen (Heliox) can be given as a temporising measure to reduce the impact of airway swelling [140, 141].

Oxygen should only be insufflated through the AEC in extremis because of the risk of barotrauma. It is essential to ensure that the tip of the catheter is above the carina and that there is a route for exhaled gas. Flows should not exceed 1–2 l.min⁻¹. In this situation, reintubation will usually be required.

Table 7 Sequence for use of an airway exchange catheter for reintubation.

1	Position the patient appropriately
2	Apply 100% oxygen with CPAP via a facemask
3	Select a small tracheal tube with a soft, blunt bevelled tip (for example, the tube developed for use with an intubating LMA (Intavent Direct Ltd, Maidenhead UK).
4	Administer anaesthetic or topical agents as indicated
5	Use direct or indirect laryngoscopy to retract the tongue and railroad the tracheal tube (with the bevel facing anteriorly) over the AEC
6	After reintubation, confirm the position of the tracheal tube with capnography

3 Reintubation using an AEC. This is a complex procedure. Full monitoring, skilled assistance and essential equipment should be available (Table 7).

4 High-pressure source (jet) ventilation via an AEC during airway rescue. Jet ventilation via an AEC aims to avoid life-threatening hypoxia, rather than achieve full ventilation. Familiarity with the equipment and technique is essential. Barotrauma, resulting from AEC migration and subcarinal jet ventilation, is a potentially serious complication, so this technique should only be considered as a last resort and only used when there is a leak around the AEC enabling expiratory flow [134, 137]. The patency of the upper airway, using airway manoeuvres and/or adjuncts to allow expiration, further assists the avoidance of barotrauma. Many high-pressure source ventilation devices are available, but the safest incorporate a pressure sensor that stops gas flow above a pause pressure of 10–20 cmH₂O. The risk of barotrauma can be reduced by using a minimal effective inflation pressure, ensuring that the chest falls to the neutral position before further inflation, and a short inspiratory time.

In addition to barotrauma, the risks associated with AECs include direct perforation of the tracheal mucosa, interstitial pulmonary emphysema [133–136, 142, 143] and dislodgement (due to poor patient compliance, poor supervision, inadequate fixation of the AEC or airway manipulation).

Postpone extubation: extubation is an entirely elective process. At times, the threat of airway compromise is so severe that extubation should not take place. Postponing extubation for a few hours, or in some cases for a few days, may be the most appropriate course of action. A delay may allow airway oedema to

resolve and increase the chances of successful extubation. It is a sensible choice if there is a potential need to return to theatre within 24 hours. It may be the best option to match the availability of skilled, experienced personnel with the period of greatest risk; for example, it may be safer not to extubate the trachea of a patient with a very difficult airway in the late evening.

If the patient is transferred to a critical care area, there should be a written emergency reintubation plan, as recommended by NAP4 [144].

Elective surgical tracheostomy: tracheostomy should be considered when airway patency may be compromised for a considerable period due to pre-existing airway problems, the nature of surgery (for example, free flap reconstruction) or the extent of tumour, swelling, oedema or bleeding. The anaesthetist and surgeon should discuss these concerns during the planning or preparation steps and a decision made to place a tracheostomy electively.

The decision to perform tracheostomy is informed by: (1) the extent of airway compromise at the end of surgery; (2) the likelihood of postoperative airway deterioration (usually due to swelling); (3) the ability to rescue the airway; and (4) the expected duration of significant airway compromise.

Tracheostomy reduces the risk of glottic damage compared with a long-term use of a tracheal tube, and is particularly important if the patient has laryngeal oedema, or if slow resolution of a problem airway is anticipated. In addition, rapid postoperative emergence is possible without fear of unplanned extubation or failure to reintubate. Postoperative nursing in a high dependency care unit can be followed by specialist ward care.

Prophylactic (rescue) subglottic cannula: transtracheal cannulae do not provide a definitive airway, but in situations where they have been inserted at induction for an anticipated difficult airway, they can be left in situ [145]. The ‘insurance’ of having a transtracheal catheter in place and being able to insufflate oxygen or ventilate with a high-pressure source can be life-saving, but must be balanced against potential complications, including barotrauma, displacement, obstruction or kinking, trauma, haemorrhage, and infection. The same level of postoperative care and monitoring is required as for a tracheostomy. They can be left in place for up to 72 hours.

Step 4: post-extubation care: recovery and follow-up

Life-threatening complications following extubation are not restricted to the immediate postoperative period. Anaesthetists have a continuing duty of care to the patient [146].

Oxygen should be administered during transfer to recovery, and portable monitoring should be considered if the recovery area is distant from the operating theatre or if the patient's condition is unstable.

Staffing and communication. Trained staff should nurse the patient until airway reflexes have returned and the patient is physiologically stable. There should be one recovery nurse for each patient, with never fewer than two personnel in recovery. An appropriately skilled anaesthetist must be immediately available [147, 148].

Good communication is essential. Surgical and anaesthetic concerns for recovery and the postoperative period should be discussed at the end of the case. A clear verbal handover and written instructions should be available for both recovery and the ward or high dependency unit. In high-risk cases, the on-call team should be briefed about the patient and a written airway management plan should be in place. A calm atmosphere and reassurance are particularly helpful for the patient with airway compromise as anxiety increases the work of breathing.

Observations and warning signs. Observations should include level of consciousness, respiratory rate, heart rate, blood pressure, peripheral oxygen saturation, temperature and pain score. Capnography (using a specially designed facemask) has the potential to aid early detection of airway obstruction [149, 150]. Close observation of the patient is necessary during recovery. A pulse oximeter is not designed to be a monitor of ventilation. Oximeters can give incorrect readings in a variety of circumstances and should never be relied upon as the sole monitor [151-154].

Warning signs include early problems with the airway (stridor, obstructed pattern of breathing, agitation) and resulting from surgery (drain losses, free flap perfusion, airway bleeding, haematoma formation and airway swelling), and late problems after return to the ward, relating to mediastinitis and airway injury.

Mediastinitis can occur after airway perforation, for example, after difficult intubation, and is characterised by pain (severe sore throat, deep cervical pain, chest pain, dysphagia, painful swallowing), fever and crepitus [57]. Patients should be informed about the symptoms of mediastinitis, and advised to seek medical advice should they occur.

The ASA closed-claim analysis suggests that airway trauma most commonly involves the larynx (after routine intubation), the pharynx and the oesophagus (after difficult intubation) [56]. Pharyngeal and oesophageal injury are difficult to diagnose, with pneumothorax, pneumo mediastinum or surgical emphysema present in only 50% of cases.

A patient who is agitated or complains of difficulty breathing should never be ignored, even if objective signs are absent.

Equipment and monitors. A difficult airway trolley should be immediately available, as should relevant items such as clip removers and wire cutters. Standard monitoring should be continued in recovery. Capnography should be available.

Location and safe transfer. All extubations should be supervised by an anaesthetist. 'At-risk' extubation should occur in the operating theatre. Patients in whom there is concern about the airway should either stay in recovery or go to a critical care environment. During transfer to recovery or critical care areas, the patient should be supervised by an anaesthetist.

Transfer of 'at-risk' patients from intensive care to the operating theatre for extubation may be appropriate to ensure availability of necessary equipment and expertise.

Respiratory care for patients with airway compromise. Patients with airway compromise should be nursed upright, and administered high-flow humidified oxygen. End-tidal carbon dioxide monitoring is desirable. The patient should be kept starved, as laryngeal competence may be impaired despite full consciousness [48]. Factors that would impede venous drainage should be avoided. Deep breaths and coughing to clear secretions should be encouraged. In patients with OSA, a nasopharyngeal airway may overcome upper airway obstruction. If the

patient uses a CPAP device at home, it should be available for use in recovery and on the ward.

Steroids reduce inflammatory airway oedema resulting from direct airway injury (surgical/anaesthetic/thermal/chemical) [105-107, 155], but have no effect on mechanical oedema secondary to venous obstruction (e.g. neck haematoma). The evidence suggests that all steroids are equally effective, provided they are given in adequate doses (equivalent to 100 mg hydrocortisone every 6 hours). Steroids should be started as soon as possible in patients who are at high risk of inflammatory airway oedema and continued for at least 12 hours. Single-dose steroids given immediately before extubation are ineffective [105-107, 155, 156].

If upper respiratory obstruction/stridor develops, nebulised adrenaline (1 mg) may reduce airway oedema. Heliox may be helpful, but limits the $F_{I}O_2$ [140, 141, 157-160].

Analgesia. Good analgesia optimises postoperative respiratory function. Sedative analgesia should be avoided or titrated cautiously. Effective anti-emesis is important.

Documentation and recommendations for future management. Clinical details and instructions for recovery and postoperative care should be recorded on the anaesthetic chart. Difficulties should be documented in the 'Alerts' section of the medical notes and in the local difficult intubation database. Details of airway management and future recommendations should be recorded. A letter should be sent to the patient's general practitioner and a copy given to the patient (DAS Airway Alert form), who should also be given a full explanation when they are able to retain this information [161, 162]. The patient should also be warned about the delayed symptoms of airway trauma and advised to seek medical help should they develop. Patients with difficult airways should be advised to register with an accessible, dependable database such as MedicAlert.

Conclusion

Guidelines are useful in infrequent, life-threatening situations, and have been shown to improve outcomes [16, 163-170]. Several national guidelines for manage-

ment of the airway have been published, but none has addressed extubation in detail [11-15, 18, 19].

Extubation differs from intubation, in that it should always be an elective process with adequate time available to the anaesthetist for methodical management. Extubation practice is highly variable, and is not often formally addressed in training. Technical and non-technical factors can contribute to adverse events at extubation [36, 135, 171, 172], but outcomes are improved by planning, organisation and communication [65, 66, 173].

The DAS extubation guidelines promote the concept of an extubation strategy, involving a stepwise approach to planning, preparation and risk stratification, aimed at clear identification and management of patients 'at risk' during extubation.

The evidence base for extubation practice is limited, so inevitably some of the recommendations in these guidelines are based on expert opinion. Awake extubation is the preferred technique for most patients. However, deep extubation, laryngeal mask exchange, remifentanyl infusion and the use of airway exchange catheters may be beneficial in certain clinical situations. Delaying extubation or performing an elective tracheostomy should be considered when it is unsafe to extubate.

Representing the first attempt specifically to address extubation in a national guideline, we commend this document to the anaesthetic community, and hope that it will be used to inform clinical practice with the same degree of success as the DAS difficult intubation guidelines.

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Competing interests

Dr Patel has received an honorarium from the Laryngeal Mask Company and has received free samples of single-use LMAs that have been used for evaluation and research.

Dr Popat has received free samples of airway equipment for evaluation and research and support for workshops from Intavent Direct UK, Intersurgical UK, KARL STORZ Endoscopy (UK) Ltd and Smiths Medical.

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Appendices

Appendix 1: Laryngospasm

Laryngospasm is a complication of airway manipulation, that can adversely affect patient outcome [36, 174]. It is an exaggeration of the normal glottic closure reflex, a response to airway stimulation. Although there is some evidence from animal studies that hypoxia and hypercapnia may have an inhibitory effect on laryngospasm, it is untrue that the vocal cords will open before death occurs [175]. A large prospective Scandinavian study found an overall incidence of laryngospasm of 8.7/1000 patients, but it is more common in children, smokers, patients with pre-existing airways infections, and following the use of specific anaesthetic agents [32]. Procedures involving airway manipulation, increased secretions, and blood and surgical debris around the glottic area, particularly during light planes of anaesthesia, are associated with higher risks of laryngospasm [176, 177].

The precise pathophysiological mechanism underlying laryngospasm remains unclear, but the end result is a persistent apposition of the vocal cords [25, 27, 178]. Classically, laryngospasm presents with a characteristic inspiratory ‘crowing’ sound. If the obstruction worsens, marked suprasternal recession (‘tracheal tug’), use of accessory respiratory muscles and paradoxical movements of the thorax and abdomen may develop. Complete obstruction presents with silent inspiration. If unrelieved, laryngospasm may lead to post-obstructive pulmonary oedema and can progress to hypoxic cardiac arrest and death [32, 33, 35, 179–181].

The management of laryngospasm can be divided into strategies for prevention and for treatment.

Strategies to prevent laryngospasm at extubation

The risk of laryngospasm is greatest if extubation is attempted in a lighter plane of anaesthesia. Suction should be performed under direct vision with the patient deeply anaesthetised, to ensure that the upper airway is clear of any debris; further stimulation should be avoided until the patient is awake [177]. Topical lidocaine sprayed onto the vocal cords at induction has been shown to reduce the risk of laryngospasm following short procedures [182, 183]. Airway reactivity

varies with anaesthetic agent, with sevoflurane and propofol being the least irritant [29, 184–188]. Other adjuncts that have been used to prevent laryngospasm include intravenous lidocaine, doxapram, magnesium, and ketamine [104, 181, 189], and acupuncture [190].

Strategies to treat laryngospasm at extubation

Laryngospasm is most commonly seen in the post-extubation phase of anaesthesia, either in theatre or in the recovery area, but can also occur with a supraglottic airway device in situ [36]. Appropriate equipment, monitoring and personnel should be available throughout the theatre suite.

The management of laryngospasm is summarised in Table A1.

Treatment of laryngospasm

- 1 Call for help
- 2 Apply continuous positive airway pressure with 100% oxygen using a reservoir bag and facemask whilst ensuring the upper airway is patent. Avoid unnecessary upper airway stimulation
- 3 Larson's manoeuvre: place the middle finger of each hand in the 'laryngospasm notch' between the posterior border of the mandible and the mastoid process whilst also displacing the mandible forward in a jaw thrust. Deep pressure at this point may help relieve laryngospasm
- 4 Low-dose propofol e.g. 0.25 mg.kg⁻¹ intravenously may help

If laryngospasm persists and/or oxygen saturation is falling:

- 5 Propofol (1–2 mg.kg⁻¹ intravenously) Whilst low doses of propofol may be effective in early laryngospasm, larger doses are needed in severe laryngospasm or total cord closure
- 6 Suxamethonium 1 mg.kg⁻¹ intravenously. Worsening hypoxia in the face of continuing severe laryngospasm with total cord closure unresponsive to propofol requires immediate treatment with intravenous suxamethonium succinylcholine. The rationale for 1 mg.kg⁻¹ is to provide cord relaxation, permitting ventilation, re-oxygenation and intubation should it be necessary
- 7 In the absence of intravenous access suxamethonium can be administered via the intramuscular (2–4 mg.kg⁻¹), intralingual (2–4 mg.kg⁻¹) or intra-osseous (1 mg.kg⁻¹) routes
- 8 Atropine may be required to treat bradycardia
- 9 In extremis, consider a surgical airway

Appendix 2: Post-obstructive pulmonary oedema

The negative intrathoracic pressure created by forceful inspiratory efforts against an obstructed airway can lead

to post-obstructive (non-cardiogenic) pulmonary oedema. The commonest cause is laryngospasm (> 50%), but post-obstructive pulmonary oedema may also occur if a patient forcibly bites on a tracheal tube or LMA completely occluding the lumen [93, 94, 191]. The condition presents with dyspnoea, agitation, cough, pink, frothy sputum and low oxygen saturations. Diffuse, bilateral alveolar opacities consistent with pulmonary oedema are seen on the chest radiograph [192]. Differential diagnosis includes the other causes of acute pulmonary oedema and aspiration of gastric contents.

Post-obstructive pulmonary oedema occurs after 0.1% of all general anaesthetics [32, 193, 194]. It is more common in young muscular adults (male:female ratio 4:1) [195].

Prompt diagnosis and management usually result in clinical and radiological resolution within a few hours (unless there are secondary complications), although delayed presentation of up to two and a half hours has been described [192,193]. Death is rare and usually attributable to hypoxic brain injury at the time of the airway obstruction.

The pathophysiology is uncertain and is likely to be multifactorial, but negative pleural pressure is the most important.

Negative pleural pressures are generated by forceful inspiratory efforts, which increase the hydrostatic pressure gradient across the pulmonary capillary wall and cause fluid leak into the interstitial space. Efforts to exhale against airway obstruction are protective as they result in PEEP, which reduces the capillary wall pressure gradient and fluid leak into the interstitium; PEEP also counters alveolar collapse and de-recruitment.

Negative intrathoracic pressure results in increased venous return (preload) to the right ventricle and increase in the pulmonary capillary blood volume. Hypoxic pulmonary vasoconstriction facilitates fluid shifts into the interstitium. Right ventricular afterload also increases as hypoxia, acidosis and negative intrathoracic pressure increase pulmonary vascular tone. This may result in a shift of the interventricular septum into the left ventricular outflow tract, increasing left ventricular diastolic dysfunction and promoting pulmonary oedema.

Together with reactive catecholamine release, hypoxia, hypercarbia and acidosis cause systemic and pulmonary vasoconstriction, increasing left and right ventricular afterload [34, 196]. Increased hydrostatic pressure in the pulmonary capillaries causes disruption of the alveolar capillary membrane (stress failure), increasing permeability, and may contribute to the development of pulmonary oedema, or cause frank bronchial bleeding [197, 198], although the generally benign nature and rapid resolution of post-obstructive pulmonary oedema suggest that this is not the predominant mechanism.

Post-obstructive pulmonary oedema may be prevented through use of a bite block during emergence [199]. Should biting occlude the tracheal tube, deflation of the cuff may allow some inward gas flow and reduce negative intrathoracic pressure.

The management of post-obstructive pulmonary oedema is shown in Table 8.

Table 8 Management of post-obstructive pulmonary oedema.

- 1 Treat the cause: relieve the airway obstruction
- 2 Administer 100% O₂ with full facial CPAP mask. In addition to relieving upper airway obstruction, CPAP may reduce oedema formation by increasing mean intrathoracic pressure and minimise alveolar collapse by increasing functional residual capacity, improving gas exchange and reducing the work of breathing
- 3 Nurse the patient sitting upright
- 4 If there is fulminant pulmonary oedema with critical hypoxaemia, tracheal intubation and mechanical ventilation with PEEP are necessary. Less severe hypoxia responds to supplemental oxygen and/or non-invasive ventilation, or CPAP [200]
- 5 Intravenous opioids may help reduce subjective dyspnoea
- 6 Chest radiography may exclude other complications of difficult airway management and causes of hypoxia (gastric aspiration, pre-existing infection, pneumothorax, barotrauma, pulmonary collapse)
- 7 Frank haemoptysis may necessitate direct laryngoscopy and/or flexible bronchoscopy
- 8 Diuretics are often administered, but their efficacy is unproven [199]

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