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Safe tracheal extubation after general anaesthesia

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Learning objectives

By reading this article, you should be able to:

- List the complications occurring during emergence, extubation and in recovery.
- Detail the factors that increase the risks of adverse events.
- Explain how to optimise conditions before tracheal extubation.
- Discuss techniques to reduce complications at extubation.

Key points

- Complications during emergence, extubation and in the PACU are common and can be life-threatening.
- An extubation plan should be formulated before anaesthesia and consider patient-related, anaesthetic, surgical and human factors.
- The patient's clinical condition should be optimised for extubation.
- Awake extubation is the standard technique.
- Extubation is an elective procedure, and removal of the tracheal tube immediately after general anaesthesia may not always be the safest approach.

Tracheal extubation generates less interest than tracheal intubation. Research, guidelines and clinical anecdotes tend to focus on airway management at the beginning of anaesthesia, and it is rare for the challenges of extubation to receive as much attention. Despite the focus on intubation, extubation and emergence from general anaesthesia are not without risk. The Royal College of Anaesthetists and Difficult Airway Society (DAS) 4th National Audit Project (NAP4) found that almost a third of major airway complications occurred during emergence and in the recovery period. Two cases resulted in death and one in severe brain injury, and there were 10 emergency surgical airways attempted.[1] Patients undergoing oral or head and neck surgery accounted for almost 50% of these cases and obesity was a common comorbid condition.[1] A prospective survey by Asai and colleagues found that respiratory complications after extubation and in the post-anaesthesia care unit (PACU) were much more common than complications occurring with tracheal intubation.[2] Data from the American Society of Anesthesiologists' (ASA) closed claims database found that 18% of insurance claims for death or brain damage arising from management of the difficult airway occurred during or after extubation.[3] Although complications at emergence and in the PACU may appear minor and transient, the NAP4 project shows that they can result in long-term injury and death.[1]

This article describes the physiological changes and complications that occur during tracheal extubation and emergence from general anaesthesia. The DAS guidelines on safe extubation after surgery are introduced and approaches to extubation explained.[4] We describe specific techniques used to manage the 'at-risk' airway. Weaning and extubation in the ICU are beyond the scope of this article.

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Problems encountered during emergence, extubation and in recovery

Physiological effects and potential morbidity

Most of the adverse effects that can occur during emergence and extubation result from airway obstruction or exaggerated

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airway reflexes. The cranial nerves innervating the pharynx and larynx mediate reflexes that protect and maintain a patent airway. Anaesthesia impairs these reflexes, allowing airway manipulation and insertion of airway devices. During the transition from 'asleep' to 'awake', the sensitivity of these reflexes is exaggerated.[5,6] The problems encountered are summarised in Table 1. Airway and respiratory complications are the most common.[5,7,8]

Airway obstruction

The NAP4 report found that airway obstruction was the primary cause of all airway complications at the end of anaesthesia and in the PACU.[1] A patent airway is a prerequisite for successful extubation but there is a high risk of airway obstruction during emergence. Although a difficult airway at induction of anaesthesia is likely to remain difficult, easy airway management at the start of anaesthesia can be falsely reassuring and the anaesthetist may find that the airway they are managing at the end of the procedure is very different.

Risk factors for airway obstruction

The causes of airway obstruction during emergence and extubation are summarised in Table 2. Factors specific to the patient may be present at induction or exacerbated by surgery and anaesthesia.

Residual neuromuscular block

Residual neuromuscular block as a result of incomplete antagonism of neuromuscular blocking drugs (NMBDs) is common and is associated with postoperative airway complications.

Residual neuromuscular block most commonly presents as airway obstruction. Respiratory dynamics may appear normal despite a significant degree of residual paralysis because the muscles of the upper airway and pharynx are more sensitive and take longer to recover. Inadequate ventilation and suppression of the hypoxic chemoreflex is common, and together, these factors combine to make the extubation period hazardous unless reversal of neuromuscular block is complete.[14]

The most commonly used measure of neuromuscular block is the train-of-four (TOF) ratio, which assesses the strength of muscle twitch response of the fourth stimuli compared with the first. For many years, a TOF ratio of 0.7 was considered adequate, with such patients able to generate good tidal volumes and cough, however studies have shown that pharyngeal dysfunction and increased aspiration risk are still present with a TOF ratio <0.9.[15] A recent meta-analysis demonstrated that many patients arrive in the PACU with residual neuromuscular block, 12% have a TOF ratio of <0.7 and 41% <0.9.[9] Use of a neuromuscular monitoring device is mandatory whenever NMBDs are used.[16] A simple nerve simulator relies on qualitative assessment of muscle twitch by the anaesthetist, which is unreliable; therefore current guidelines recommend a quantitative neuromuscular monitoring device is used.[14,16] A TOF ratio of ≥0.9 is recommended before extubation.[9,15]

Neuromuscular block can be antagonised with neostigmine or sugammadex, but sugammadex is only effective if rocuronium or vecuronium have been given. Reversal of neuromuscular block is faster with sugammadex than neostigmine and is associated with fewer adverse effects including a lower incidence of residual postoperative paralysis.[15] A peripheral nerve stimulator should be used with sugammadex as an insufficient dose may result in a recurrence of neuromuscular block after reversal or 'recurarisation', caused by the redistribution of free rocuronium from the plasma back to the effect site at the neuromuscular junction.[17] After giving sugammadex, it is important to consider how

Table 1 Effects of extubation and emergence from general anaesthesia with incidence as percentage where available.[2,4–13] *General anaesthesia for noncardiac surgery.

Cause	Effect	Incidence
Airway irritation	Coughing and bucking	18–66%
	Laryngospasm	17–25%
	Desaturation (Sp_{O_2} <90%)	24%
	Inadequate reversal	5–10%
	Post-obstructive pulmonary oedema	0.1%
	Bronchospasm	1%
Reduced level of consciousness/obtunded reflexes	Breath holding	13–20%
	Airway obstruction	5–19%
	Apnoea/hypoventilation	2–9%
	Vomiting/aspiration	2/0.5%
	Laryngeal incompetence	
Cardiovascular changes	Hypertension/tachycardia	10% (haemodynamic instability)
	Arrhythmias	7%*
	Raised intracranial pressure	
	Raised intraocular pressure	
	Myocardial ischaemia	
	Flap disruption/bleeding at surgical site	
Trauma	Dental damage	0.02%
	Airway oedema	
Drug effect	Residual neuromuscular block	5–10%
	Masseter spasm	

Table 2 Patient-related, surgical and anaesthetic factors that contribute to airway obstruction during emergence and extubation.

Patient-related	Obesity
	Obstructive sleep apnoea
	Smoker
	C-spine immobility
	History of head and neck radiotherapy
	Pharyngeal obstruction (tonsillar/adenoidal hypertrophy)
	Craniofacial abnormalities (micrognathia, maxillary hypoplasia)
	Neuromuscular disorders (bulbar weakness)
	Connective tissue disorders
	Storage diseases
	Chronic renal failure
	Laryngomalacia
Surgical	Airway soiling (blood, secretions)
	Swelling
	Vocal cord damage
	Neck haematoma
	Trendelenburg position (facial and airway oedema)
	Fixation of cervical spine or facial bones (causes reduced head and neck mobility)
Anaesthetic	Anaesthetic agents (reduce consciousness, impair reflexes, reduce muscle tone)
	Laryngospasm
	Residual neuromuscular block
	Glottic oedema
	Airway device occlusion (from biting, secretions or blood)

neuromuscular block will be re-established if required for reintubation. The manufacturer recommends using a benzylisoquinolinium NMBD if neuromuscular block is required within 24 h of sugammadex. There is evidence to suggest that rocuronium can be used within this period provided a rapid sequence induction is not required. If neuromuscular block is needed within 3 h of sugammadex, the dose of rocuronium should be increased to 1.2 mg kg^{-1}.[17]

Laryngospasm

Laryngeal spasm is a common complication of general anaesthesia and results from direct irritation of the vocal cords by blood, saliva or instrumentation, or indirectly from surgical stimulation. Contraction of the muscles of the larynx causes adduction of the vocal cords and airway obstruction.[5,6]

Partial airway obstruction presents with inspiratory stridor and increased airway pressure but complete obstruction is silent. If untreated, laryngospasm can progress to hypoventilation, hypoxaemia and ultimately hypoxic cardiac arrest.[4,7]

Laryngospasm during emergence and extubation is avoided by ensuring sufficient depth of anaesthesia before manipulation of the airway, removal of airway blood and secretions, and minimising head and neck movements during transfer.[4] Specific drugs may also be beneficial (see below).

Post-obstructive pulmonary oedema

Post-obstructive pulmonary oedema (POPO) can develop after an episode of airway obstruction.[6] It was noted in 10% of all anaesthesia-related airway complications in the NAP4 study.[1]

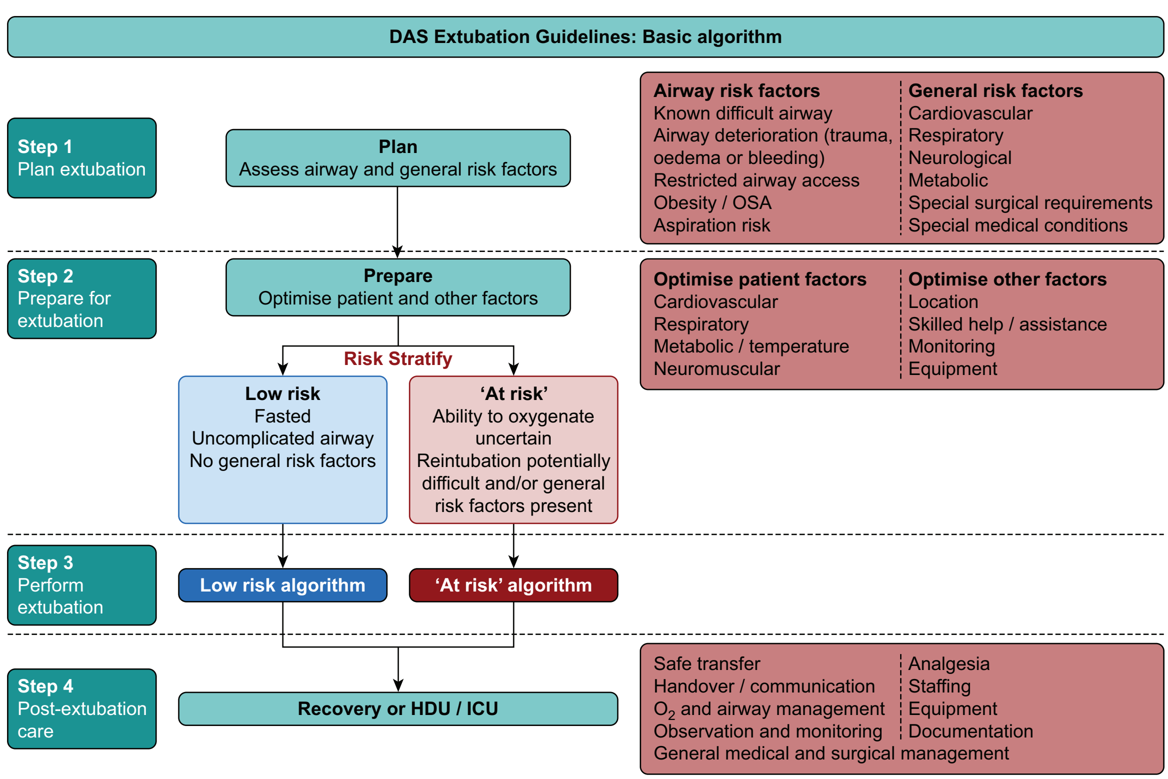

Fig 1 Difficult Airway Society (DAS) extubation guidelines: basic algorithm. Reproduced from Popat and colleagues,[4] with permission from the Association of Anaesthetists and Blackwell Publishing Ltd. HDU, high dependency unit; OSA, obstructive sleep apnoea.

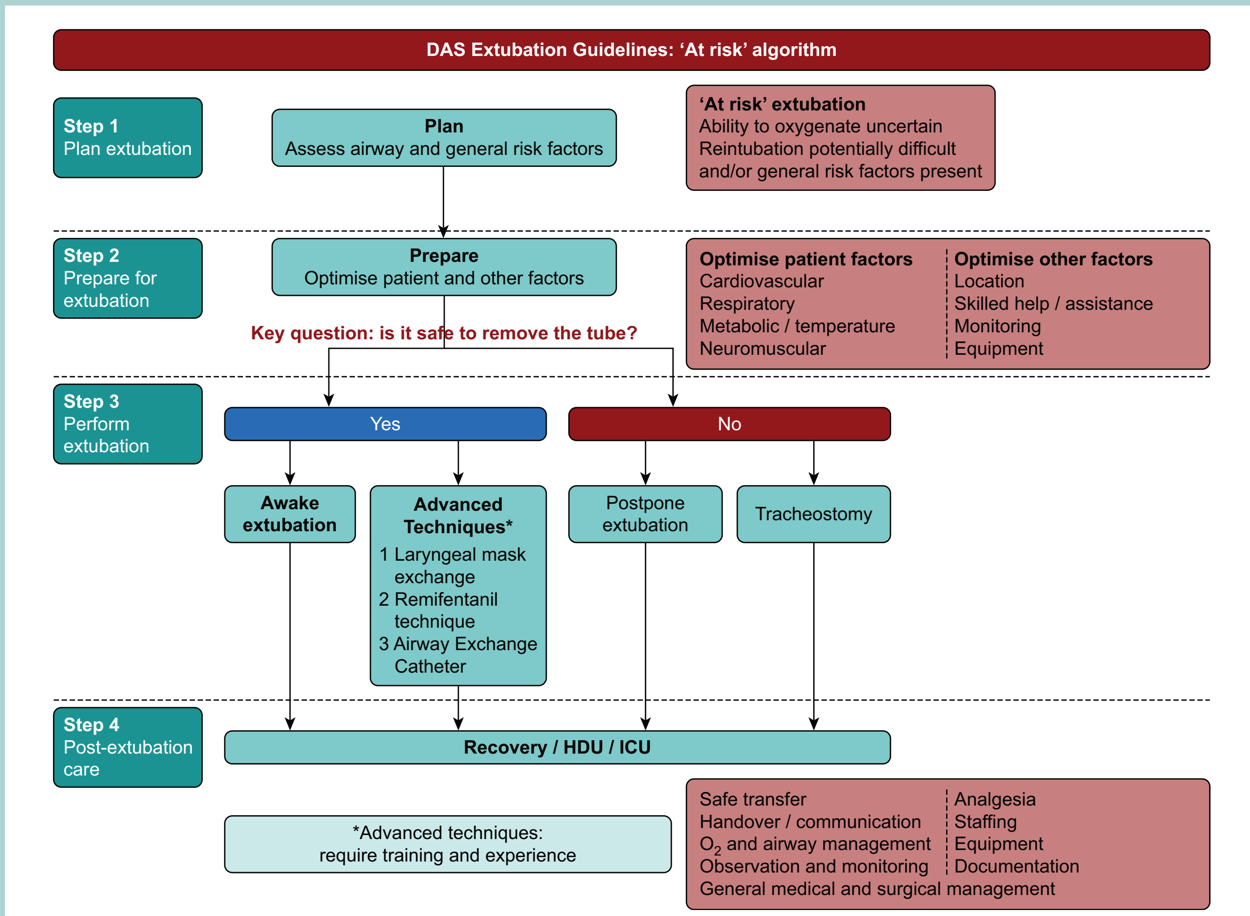

Fig 2 Difficult Airway Society (DAS) extubation guidelines: 'at-risk' algorithm. Reproduced from Popat and colleagues,[4] with permission from the Association of Anaesthetists and Blackwell Publishing Ltd. HDU, high dependency unit.

This complication is caused by a forced inspiratory effort against a closed glottis or an occluded airway. This generates a negative intrathoracic pressure that alters the Starling forces across the pulmonary capillaries and alters cardiac filling pressures and afterload. The result is movement of fluid into the alveoli and pulmonary interstitium with pulmonary oedema despite normal cardiac function. Direct mechanical stress, acidosis and hypoxia may also contribute by disrupting the alveolar epithelium and pulmonary capillaries.[10] Post-obstructive pulmonary oedema typically occurs in young, muscular adults and can follow airway obstruction of any cause, although laryngospasm is the most common.[6] Patients present with a cough, pink frothy sputum and hypoxia. Chest radiographs show features of pulmonary oedema. Management is supportive with admission to the high dependency unit (HDU) for oxygen supplementation and application of continuous positive airway pressure; in some cases, diuretics have been used.[10]

Inadequate ventilation

Opioids and anaesthetic agents obtund the central respiratory response to increased Pa_{CO_2} and hypoxia, reducing ventilatory drive.[14] Poorly controlled pain and residual neuromuscular block may prevent a patient from generating adequate tidal volumes. Pulmonary atelectasis results in ventilation/perfusion mismatch and increases the work of breathing.[5,7] Although ventilation may be compromised, patients will have an increased oxygen demand at the end of surgery, particularly those with a systemic inflammatory response or sepsis.

Environmental and human factors during emergence from anaesthesia

Human factors also increase the risk of complications during emergence and extubation. The task load for the anaesthetist at the end of surgery is high and the environment is less controlled than at induction. The patient's airway may be less accessible at the end anaesthesia because of positioning for surgery, and there are additional stressors such as extraneous noise and fatigue.[4,18]

Management of emergence, extubation and recovery

There is little evidence from RCTs and meta-analyses for managing extubation but it is clear that there is no one single technique suitable for all patients.[4] There is general agreement that the extubation strategy should be considered before anaesthesia, to assess the individual risk for each patient and allow sufficient time for planning and preparation.[4] Preoperative plans can then be modified depending on intraoperative events.[1] During extubation, as with intubation, the aim is to ensure adequate delivery of oxygen to the lungs. In 2012 DAS published guidelines on the management of tracheal extubation in adults. This was the first guideline to focus specifically on tracheal extubation and is applicable to all adults undergoing general anaesthesia, not just those with a difficult airway. The guidelines present a systematic approach to stratify patients into 'low' or 'at-risk' groups and outline some extubation techniques (Figs. 1 and 2).[4]

Planning and preparation for extubation

Preparation creates conditions that favour safe and successful extubation (Table 3). A safe extubation depends on good communication between the anaesthetist, surgeon and operating theatre team, particularly for the 'at-risk' airway.[4]

Table 3 An ABC approach to extubation: essential considerations when preparing for extubation at the end of surgery.

Airway	Ensure the airway is patent Patient is able to protect airway adequately Consider inserting a bite block Remove any throat packs
Breathing	Adequate ventilation – oxygenation and removal of CO_2 • Assess Sp_{O_2} and $P_{E'CO_2}$ • Regular ventilatory pattern, breathing with steady rate and tidal volumes • If using a supported ventilation mode, pressure support and PEEP should be minimal • Give 100% oxygen
Circulation	Stable blood pressure, heart rate and rhythm • Normotension without need for high levels of inotrope or vasopressor support • Adequate fluid balance, normal or improving lactate • No significant acidosis • Arrhythmias treated and controlled
Drugs	Confirm reversal of neuromuscular block Ensure adequate analgesia
Environment	Temperature • Maintain normothermia Equipment • Airway management equipment readily available Positioning • Head up or left lateral Location • Suitable location with adequate monitoring and assistance
Human factors	Timing • Consider time of day, staff availability, levels of fatigue • Appropriate assistance/expertise available • Formulate a plan for extubation failure – particularly in high-risk cases

Both the patient's clinical condition and situational factors are important. The necessary equipment, monitoring and staff should available.[1,4,18]

Depth of anaesthesia

Extubation should be carried out with the patient either fully awake or deeply anaesthetised as attempting extubation in an intermediate plane of anaesthesia is more likely to result in complications.[4] In the fully awake patient who is breathing spontaneously, airway protective reflexes have returned and the patient is able to protect and maintain a patent airway. The presence of the tracheal tube may trigger coughing, straining and sympathetic activation resulting in tachycardia and hypertension.[5–7] Tracheal stimulation can be avoided by reducing movement of both the patient and tracheal tube and minimising oropharyngeal suctioning. If the haemodynamic or respiratory effects secondary to coughing and bucking are undesirable, a modified technique such as deep extubation may be considered (see below).

Pharmacological interventions during emergence and extubation

Various drugs have been used to reduce coughing and cardiovascular changes at extubation. Lidocaine i.v. or topically, sprayed onto the vocal cords or instilled into the tracheal tube cuff, has been shown to reduce coughing and haemodynamic changes.[5,6,19] Low doses of propofol and ketamine, given as a bolus, can reduce the incidence of coughing. A number of other drugs have been used to prevent hypertension and tachycardia including i.v. magnesium, beta blockers, glyceryl trinitrate (GTN) and opioids.[5,6,19]

Steroids such as dexamethasone are useful in situations where there is direct airway trauma causing inflammation but do not reduce 'secondary' swelling resulting from positioning and poor venous return.[4]

Dexmedetomidine can reduce coughing and the haemodynamic effects of extubation while avoiding the respiratory depression associated with opioids. It is currently only licensed for ICU sedation in the UK, but studies have shown it may be useful perioperatively as infusion or a bolus dose before extubation.[19]

Doxapram is a respiratory stimulant that has been used to reduce postoperative pulmonary complications, primarily hypoventilation, although it may cause hypertension and tachycardia.[4]

Planning for failure

The NAP4 report found that routine airway equipment was not readily available when airway problems occurred.[1] Airway equipment must be easily accessible and a back-up plan for extubation failure considered. A rational approach for problems after extubation is to follow published guidelines on the management of the airway at induction.[4] Those at high risk of complications should have a specific extubation and reintubation plan, which should be shared with the theatre team.

Postponing extubation

Extubation is an elective procedure. In circumstances where the airway is severely compromised, it may be safer to delay removal of the tracheal tube and transfer the patient to the intensive care unit to allow for a period of weaning. Alternatively, if the weaning period is likely to be prolonged or there is a risk of airway deterioration (e.g. from oedema), a surgical

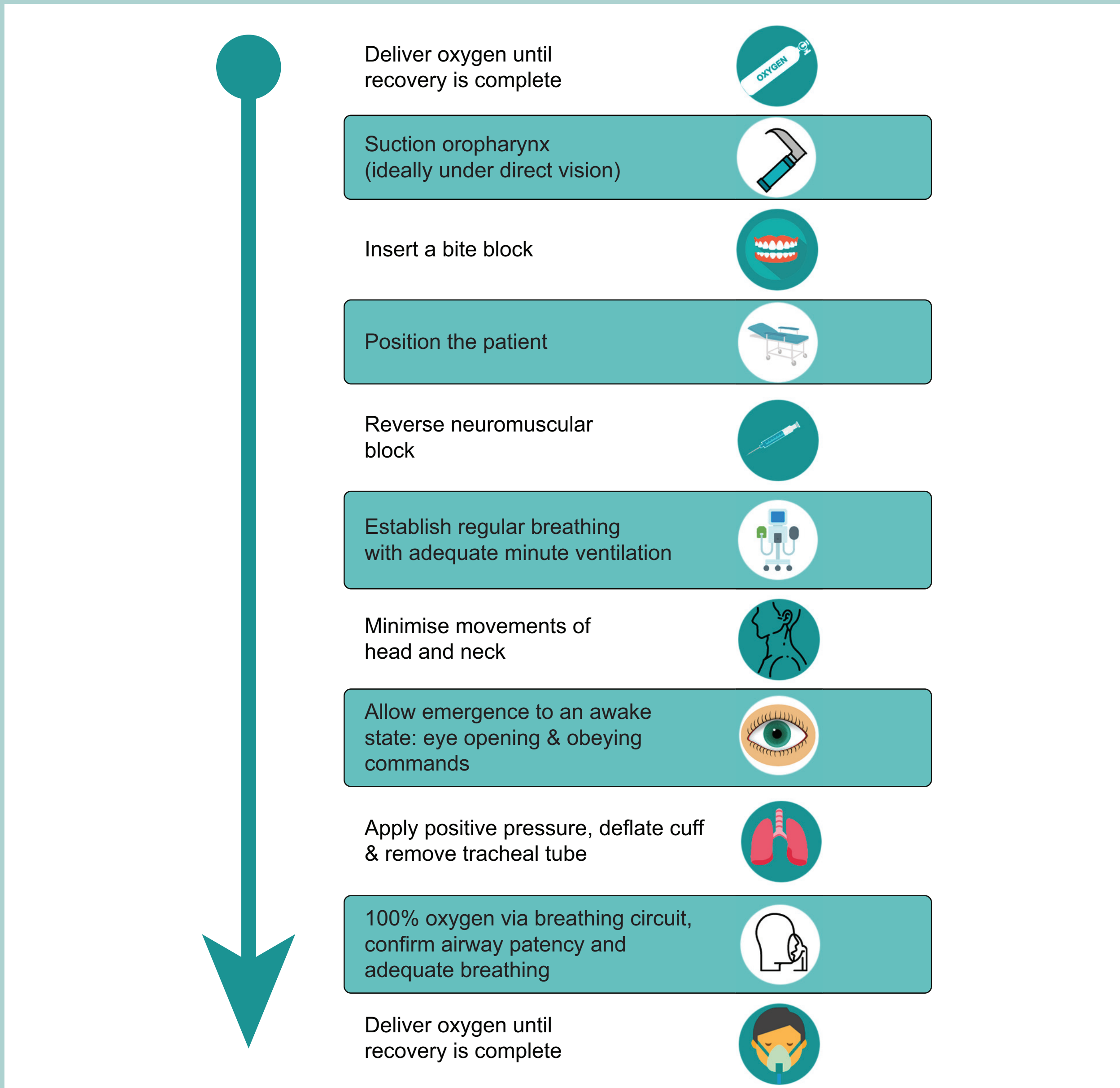

Fig 3 Key steps in performing a 'low risk' awake extubation. Adapted from Popat and colleagues.[4]

tracheostomy may be performed electively. This decision should be made jointly by the anaesthetist and surgeon.[4]

Process of extubation

The majority of patients will have an awake extubation (Fig. 3).[4] Safe extubation can take time; it should not be rushed, and this should be considered when operating lists are planned.

Positioning the patient

Extubation after anaesthesia was traditionally performed with the patient in the left lateral, head down position to protect the airway should vomiting or regurgitation of stomach contents occur.[4] In the lateral position the tongue falls forwards rather than posteriorly into the oropharynx, making it is easier to maintain a patent airway; however, respiratory mechanics are less favourable. A 2005 survey of extubation practices amongst anaesthetists in the UK and Ireland found that less than a quarter routinely performed extubation after elective surgery in the left lateral or left lateral, head down position.[11] The semi-recumbent, or head-up, position improves respiratory dynamics, which is beneficial in obese patients and those with lung disease, and it also makes airway management easier should complications occur.[4,11] The left lateral, head down position for extubation may still be appropriate if the patient is at high risk of pulmonary aspiration.[11]

Inspired oxygen

There is limited evidence on the optimum fraction of inspired oxygen during emergence and extubation. Guidelines set by DAS recommend delivering 100% oxygen to raise the expired oxygen fraction to more than 0.9, providing a 'store' of oxygen to delay the onset of hypoxia should complications occur.[4] Conversely, it has been demonstrated that the use of 100% oxygen leads to alveolar atelectasis, increasing the risk of postoperative hypoxia.[20,21] Alveolar atelectasis may occur after as little as 6 min delivery of 100% oxygen.[20] A pragmatic approach for extubation is to deliver 100% oxygen for the shortest time possible, reducing it to a more appropriate level for the individual patient's requirement.

Application of positive pressure

Recruitment manoeuvres such as a vital capacity volume breath or the application of positive end-expiratory pressure as the tracheal tube is removed aim to reverse atelectasis induced during anaesthesia. In theory, a positive pressure gradient from the lungs will expel any material that may have accumulated above the tracheal tube cuff, preventing it from falling into the airway.[5] There is no evidence that these manoeuvres improve oxygenation postoperatively, although they are regularly performed by anaesthetists and recommended in the DAS guidelines.[4,11,22]

Suction

Respiratory secretions, gastric contents and blood can collect in the upper airway. Airway suction before extubation can prevent soiling of the lung's and stimulation of airway reflex responses such as coughing and laryngospasm. Blood in the airway was a frequent feature in cases reported to NAP4, and the airway should be carefully inspected before extubation after airway surgery.[1] Ideally, suctioning should be performed under direct vision with a laryngoscope as there is a risk of soft tissue trauma if done blindly. Laryngoscopy at the end of surgery may help identify any occult blood or clots in the airway and to assess any change in intubation grade. Deep oropharyngeal suctioning is stimulating and should be performed with the patient deeply anaesthetised, especially if performed under direct vision using a laryngoscope.[4] Tracheal suction may be also be needed, but it is important to be aware that this will interrupt oxygen flow and may deplete oxygen stores.[5]

Aerosol generation and virus transmission

Tracheal extubation can result in the release of airborne particles from the respiratory tract, resulting in spread of infectious diseases transmitted by droplets or airborne transmission. The recent severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) pandemic has highlighted this risk. The production of aerosol particles during extubation is higher than during intubation, especially if the patient coughs. The risks of transmission can be reduced by appropriate use of personal protective equipment and with the use of techniques aimed to reduce patient coughing at extubation.[6,23]

Advanced techniques for extubation

The following extubation techniques need to be learnt, practiced and refined in the clinical setting, but key points are described below.

Deep extubation

Deep extubation can avoid the effects of airway irritation, in particular coughing, bucking and haemodynamic instability.[6,8] It is commonly performed after neurosurgery, ophthalmic surgery and ENT operations where an increase in intracranial, intraocular and vascular pressures can cause undesirable effects.

Spontaneous ventilation is established with adequate depth of anaesthesia using TIVA or an inhalational agent. The larynx should be suctioned under direct vision, using a laryngoscope, to prevent soiling of the trachea once the tracheal cuff is deflated. The cuff is gently deflated and adequate spontaneous ventilation confirmed before removal of the tube.[4] As the tracheal tube is removed before airway reflexes have returned, coughing and straining are less likely but airway obstruction is still a risk and airway manoeuvres and adjuncts may be required to maintain airway patency until the patient is fully awake. Deep extubation should only be carried out by those experienced in the technique. It is not appropriate for patients at risk of aspiration and in whom bag-mask ventilation or reintubation would be challenging.[8] Monitoring by appropriately trained staff is essential until the patient recovers fully from anaesthesia and is awake, breathing spontaneously and not requiring any airway support.[4,16]

Supraglottic airway device exchange

Exchanging the tracheal tube for a supraglottic airway device (SAD) provides some airway protection and patency without the cardiovascular and respiratory stimulation caused by a tracheal tube. This results in smoother emergence, avoiding major haemodynamic changes and respiratory complications such as breath holding, coughing and bucking.[6,24] SAD exchange is performed after suctioning of the airway under direct vision before the patient is breathing spontaneously. To avoid complications of airway stimulation the patient, must be deeply anaesthetised. This technique was originally described by Bailey using a Classic LMA inserted with the tracheal tube still *in situ* as this holds the epiglottis anteriorly and prevents it from folding and obstructing the larynx when the SAD is inserted.[25]

Remifentanil

Remifentanil is a potent, ultra-short acting opioid receptor agonist and, like other opioids, it obtunds cardiovascular and respiratory reflexes.[6] Infusion of remifentanil during emergence and extubation allows spontaneous breathing to be established with the tracheal tube *in situ* without the associated coughing, straining and haemodynamic changes.[4,6,19] There may already be a remifentanil infusion used during surgery or it may be started specifically for extubation. When the patient is able to follow commands and ventilation is adequate, the tracheal tube can be removed. This technique requires practice to get the timing right and careful titration to prevent respiratory depression. The infusion rate or target effect site concentration to reliably prevent coughing varies, depending on the patient and on the presence of other anaesthetic and analgesic agents.

Airway exchange catheter

An airway exchange catheter (AEC) may be considered for extubation of a difficult airway. They are hollow, semi-rigid catheters that are narrow enough to be tolerated by an awake patient, but rigid enough to provide a guide for reintubation should it be necessary.[4,7,12] The catheter is placed into the trachea via the tracheal tube before extubation. Distance markings in centimetres allow correct positioning within the airway to reduce the risk of trauma to the trachea and bronchial tree. In adults they should never be inserted to a depth greater than 25 cm from the lips.[4,13]

Catheters may have a 15 mm connector to attach to an anaesthetic circuit, a Luer lock connector for jet ventilation, or both; however, this is not recommended because of the high risk of pulmonary barotrauma.[4,12] Patients must be nursed in a high dependency environment by staff who have training and experience in managing patients with AECs. They may be tolerated for up to 72 h but should be removed as soon as possible when the airway is no longer at risk.[4] Some staged extubation kits include a soft-tipped wire that is placed in the airway rather than a catheter. Wires may be better tolerated and cause less airway trauma and inflammation. The AEC is threaded over the wire should reintubation be needed.

Postoperative care

After extubation it is important to consider postoperative care and recovery. Oxygen should be given during transfer and in the PACU until recovery is complete.[1,4,6] In situations where there is concern about airway or respiratory compromise, humidified high-flow nasal oxygen may be beneficial. The Royal College of Anaesthetists and Association of Anaesthetists have clear recommendations on minimum requirements for staffing and monitoring in recovery and PACUs.[16] If airway management has been difficult there must be clear written and verbal handover. It is good practice to document an 'airway plan' in the event of an airway emergency or return to theatre.[1,4] This plan can be summarised on an 'airway management bed head' to aid communication. All at-risk patients should be handed over to the anaesthesia team on call. Complications and adverse events should be recorded in the patient's medical notes and on a local database. It is important to explain events to the patient, when this is possible, and provide them with a written summary that should be copied to their general practitioner.[4]

Summary

Complications during emergence and extubation are common; fortunately, they are usually minor and easily treated. Airway and respiratory complications are the most frequent and can result in significant morbidity and mortality. Tracheal extubation requires a clear strategy to avoid complications and keep patients safe. This strategy should include risk assessment, planning and preparation. The patient and situational factors should be optimised before extubation and fully monitored during transfer and in the PACU. Written and verbal communication of any difficulties and plans for airway management are important. Tracheal extubation is an elective procedure; immediate extubation after general anaesthesia may be inappropriate in some scenarios.

Declarations of interest

The authors declare that they have no conflicts of interest.

MCQs

The associated MCQs (to support CME/CPD activity) will be accessible at www.bjaed.org/cme/home by subscribers to *BJA Education*.

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