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EDITORIALS

Special issue on airway management

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We are pleased to launch a special issue on airway management.

In the early 1990s, failed oxygenation was found to be the main cause of death during anaesthesia. Since then, several major efforts have been made to reduce the incidence; the societies for airway management were founded, guidelines about difficult airway management have been formulated, new reliable airway devices have been developed, and oximetry and capnography have become widely available. As a result of these efforts, the incidence of serious adverse outcomes is likely to have decreased.[1–4] Nevertheless, recent reports have indicated that life-threatening airway complications occur in a limited number of patients during anaesthesia, during a stay in intensive care units, and at emergency departments,[5–7] and that problems associated with airway management are still the main causes of anaesthesia-related death or serious complications.[8] The *British Journal of Anaesthesia* recognizes that the current strategies for airway management are still not ideal,[1 9] and thus has constantly been providing key articles about airway management.

In November 2015, the World Airway Management Meeting, which was the first joint meeting of the Difficult Airway Society (DAS) in the UK and the Society for Airway Management (SAM) in the USA, was held in Dublin. The meeting had more than 1500 delegates from all over the world and 397 abstracts presented. The success of the meeting triggered us to call for papers that aim to review the current problems associated with airway management and provide evidence-based best preventative methods and treatment methods to reduce life-threatening complications associated with airway management. Within a few months, ~80 drafts were submitted from throughout the world. Each draft underwent a strict review process, and we are pleased to have more than 10 articles accepted for the special issue. The special issue also contains the top 30 abstracts presented at the meeting. These articles, which are freely available to all readers online immediately, provide useful information that will help to make airway management much safer.

In this special issue, the articles highlight some areas for improvement in routine airway management.[10–12] In the paper by Healy and colleagues,[13] the authors attempted to find an improved prediction method for difficult tracheal intubation ('Mallampati' score) and have found that the Mallampati evaluation should be performed with the cervical spine in the neutral position in order to maximize test sensitivity. Carassiti and colleagues[14] studied the pressure exerted by the cuffs of bronchial blockers on the inner wall of the bronchi, and found that the pressure exerted by the cuffs on the bronchus cannot be estimated by the intracuff pressures and may frequently exceed the bronchial capillary pressures. Sajayan and colleagues[15] completed a UK national survey on the current practice of rapid-sequence induction of anaesthesia, and they found that the 'classical' technique is now seldom used and that there are variations in the practice among anaesthetists in the UK. They conclude that the time has come to develop consistent guidelines for rapid-sequence induction of anaesthesia.

Current methods of airway management outside the operating theatre are not ideal.[16 17] Included in this special issue is a review by Natt and colleagues,[18] who looked at effective methods of tracheal intubation in critically ill patients, and Mercer and colleagues[19] have provided a systematic review on anaesthetic management of acute airway trauma. Ucisik-Keser and colleagues[20] have searched for the most suitable airway device in patients undergoing magnetic resonance imaging of the central nervous system under deep sedation or under general anaesthesia and have found that the use of a supraglottic airway (in comparison with no airway, oral or nasal airway, or tracheal intubation) is most suitable.

Videolaryngoscopes have potential roles in patients with difficult airways, but it is still not clear which videolaryngoscopes are more suitable than others.[21 22] Kleine-Brueggeney and colleagues[23] studied six different videolaryngoscopes, and found that suitable videolaryngoscopes may differ in patients with different causes of difficult airways.

A fibreoptic bronchoscope is considered to be the most reliable device for tracheal intubation in patients with difficult airways, but considerable skill is required to perform fibreoptic intubation.[24] Baker and colleagues[25] have developed a new bronchoscopy simulator (ORSIM) and have shown that the simulator is effective in assessing subjects on both normal and abnormal airway simulations.

If oxygenation is difficult because of failed tracheal intubation and difficult ventilation via a face mask after induction of anaesthesia, all the major guidelines on difficult airway management[2–4] recommend the use a supraglottic airway as a 'rescue device'. Nevertheless, the device may fail in some patients, and thus knowledge about the incidence and the causes of failures is required.[26 27] Saito and colleagues[28] performed a validation study of a new clinical score to predict difficult ventilation through a supraglottic airway device, and found that a high score is associated with a six- to seven-fold increase in the risk of difficult ventilation through a supraglottic airway device.

If insertion of a supraglottic airway is ineffective in a 'cannot intubate, cannot oxygenate' situation, invasive access to the infraglottic airway or front-of-neck access is regarded as the last resort.[2–4] Nevertheless, it is still not clear which method of invasive access (such as cricothyrotomy or tracheostomy) and which mode of ventilation are most effective.[29–32] Rosenstock and colleagues[33] completed a cohort study, assessing the incidence of and the efficacy of emergency surgical airway after induction of anaesthesia, and they found that the failure rate of establishing an emergency airway was high. Duggan and colleagues[34] carried out a systematic review, comparing complications associated with the use of jet ventilation in patients with and without a 'cannot intubate, cannot oxygenate' emergency situation. This group found that the incidence of complications (e.g. device failure or barotrauma) is strikingly high in this emergency situation.

Airway complications are commonly associated with poor standards of care.[5 6] Therefore, it is necessary to establish a training system for routine and emergency airway management (including cognitive, psychomotor, and behavioural areas), in order to minimize serious complications.[35 36] Chrimes[37] describes a new cognitive aid (the 'Vortex')[38] to airway emergencies, to support team function and target recognized failings in airway crisis management. Kristensen and colleagues[39] offer a narrative review about the usefulness of ultrasonography in identifying the cricothyroid membrane, and have advocated the routine use of ultrasound to identify the cricothyroid membrane before induction of general anaesthesia.

We are confident that the papers published in this special issue will improve our knowledge in many aspects of airway management. We hope that it will stimulate further research in this very important area of our practice, with the aim of reducing morbidity and mortality related to airway management.

Declaration of interest

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Paediatric difficult airway management: what every anaesthetist should know!

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Airway management remains a significant cause of morbidity and mortality in anaesthetized children. Children with difficult direct laryngoscopy are an especially vulnerable group. However, most paediatric anaesthetics are administered by generalists without advanced paediatric training. This editorial is aimed at all practitioners who care for children, particularly those without advanced paediatric anaesthesia training. Our goal is to convey three important points: (i) the contributing factors for severe complications in this population; (ii) the important role of the supraglottic airway (SGA) in managing these patients; and (iii) the

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Airway management in the critically ill: the same, but different

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Airway management has had a central role in intensive care medicine even from its origins. When Danish Anaesthetist Björn Ibsen applied his airway skills to victims of the 1952–3 Copenhagen poliomyelitis epidemic, the era of Critical Care Medicine was born.[1] The importance of advanced airway management in the care of the critically patient is one reason why modern Intensive Care Medicine is still closely allied to Anaesthesia in many countries.

In many ICUs there has recently been a move to more multispecialty and even multidisciplinary staffing, both at a senior and trainee level, meaning advanced airway skills may not be reliably available. Staff are faced with increasingly obese patients with deranged baseline physiology and complex conditions who are disproportionately likely to experience airway difficulty, presenting challenges to airway safety in ICU.[2 3]

The 4th National Audit Project of the Royal College of Anaesthetists and Difficult Airway Society (NAP4)[3] highlighted the difficulties, and sometimes failings, of airway management in ICU and showed it to be a place of 'increased airway danger' compared with the operating theatre. However there are also opportunities: in the last decade airway management in anaesthesia has changed significantly. Adoption of appropriate technical and non-technical advances by the intensive care community from anaesthesia is likely to provide benefit. With updated airway management guidelines in Canada,[4] USA,[5] Germany[6] and the UK[7] in recent years, now is a good time to reflect on both the challenges and opportunities facing those managing the airway in ICU. It is also time to consider whether difficult airway guidelines developed primarily for an anaesthetic setting are appropriate for airway management of critically ill patients, both inside and outside the ICU.

Why is ICU airway management different?

It is well recognized that in special circumstances different airway management approaches are needed, reflected by a range of published strategies and algorithms for adult, paediatric, obstetric, emergency and pre-hospital populations. Airway management in the critically ill patient may occur on the ICU itself or almost anywhere else in the hospital environment. Many of these locations are remote, none are designed with airway management primarily in mind and they all present logistical challenges. While some airway interventions will be planned, most are reactive and emergent, often with the intubating team called urgently to a rapidly deteriorating patient.

Patient factors often contribute to difficulty. In the emergency setting and with a patient who may be hypoxic, obtunded, combative or all three, airway assessment is difficult and often cannot be performed to the highest standards. Rapid sequence induction will be considered appropriate in most of these patients because of lack of starvation, intra-abdominal pathology or functional gastric stasis. The vast majority will have unstable physiology – even before anaesthesia is induced. This includes pre-existing hypoxia, ventilation-perfusion mismatch that impairs preoxygenation, absolute or relative hypovolaemia and an increased risk of myocardial impairment. This lack of cardiorespiratory reserve increases the risk of profound hypoxia, hypotension, arrhythmia, cardiac arrest and death.[8 9] Induction of anaesthesia is complex, requiring modification of normal drug choices and doses. Airway management needs to be prompt and successful to prevent physiological decline. Rapid desaturation from a hypoxic baseline creates time pressure and demands rapid action. Even when airway management is successful the initiation of positive pressure ventilation may also be poorly tolerated and lead to immediate or delayed deterioration.[10]

Of note the incidence of difficult airways in the critically ill is also likely increased. Patients with known airway difficulty are often admitted to the ICU for monitoring and management including intubation, extubation or observation. Astin's UK survey[11] reported that one in 20 UK adult ICU admissions were for management of a primary airway problem and one in 16 patients had a predicted difficult airway. More pertinently, one in four of the ICUs surveyed had a patient admitted with a primary airway problem and 40% were managing at least one patient with a predicted difficult airway. Critical illness and its management can also render an anatomically 'normal' airway 'difficult' with fluid resuscitation, capillary leak syndromes, prone ventilation and long periods of intubation all contributing to airway oedema and distortion.

Importantly, but little discussed, the lack of skilled assistance and adequate equipment when managing the airways of critically ill patients may also impact on delivery of prompt, safe, skilled airway management – especially when difficulty occurs and non-standard plans are required.[3]

What then are the impacts of these multifactorial issues on the outcomes of airway management in ICU? Firstly, failure to intubate is much more likely when inducing anaesthesia in the critically ill. Failure at the first intubation attempt can be expected in 10–12%, significantly higher than during anaesthetic practice.[12–14] Complications and cardiac arrests increase significantly as the number of intubation attempts increases.[12]

Cardiac arrest during intubation on ICU is not infrequent. Over a 12 year period, with all intubations performed by an airway operator with a minimum of six months anaesthetic training, Mort reported 60 cardiac arrests occurring during 3035 out-of-theatre intubations (2%).[15] Eighty-three percent of patients who arrested experienced severe hypoxaemia (SpO_2< 70%) during intubation, including all those patients requiring ≥3 intubation attempts. Patients developing severe hypoxia required an average of almost four attempts, while those without hypoxia were nearly all intubated first time. Oesophageal intubation increased risk of cardiac arrest more than 15-fold.

Other complications are common during ICU intubation attempts. In Nolan and Kelly's 2011 review of critical care airway literature[16] the reported rates of complications included: ≥3 intubation attempts 10%, severe hypoxaemia 7%, severe hypotension 17%, oesophageal intubation 5.3%, aspiration 2.6% and cardiac arrest 2.1%. In a study of seven French units staffed by residents with a minimum of one year's experience, Jaber found that at least one severe complication occurred in 28% of intubations, including severe hypoxaemia in 26%, and cardiac arrest in 1.6%.[10] The main risk factors were pre-procedural respiratory failure and shock, whilst the presence of two operators reduced risk. The authors highlight that the use of neuromuscular blocking agents for intubation in their study (62%) was in the middle of an extremely wide spectrum quoted in the international literature (ranging from 22–80%) and attributed the wide variety of practice to a regrettable lack of recommendations for airway management in critically ill patients.[10 13]

There are of course clear differences in the post-intubation management of patients on ICU compared with anaesthetic practice. ICU patients may remain intubated for weeks and, in contrast to theatre, most ICU airway incidents take place after the airway has been secured. The UK National Reporting and Learning Centre identified that 82% of ICU airway incidents occurred after intubation, with 25% contributing to the patient's death.[17] All invasively ventilated ICU patients are subject to procedures, complex nursing care and repositioning which requires a high degree of vigilance to maintain the airway device, with success dependent on the performance of the multidisciplinary team, rather than one constantly present anaesthetist. Because of this, airway displacement and subsequent re-intubation is a constant danger in ICU, associated with high complication rates, including mortality.[3 18] Tracheostomies are used to manage around 10–19% of level 3 ICU admissions in Europe and the US, and these patients occupy a disproportionately high number of ventilator bed days.[18] The 2014 UK NCEPOD report into tracheostomy care reported complications in 23.6% of tracheostomized ICU patients, with nearly 30% of patients experiencing multiple complications.[19] In keeping with previous reports, tube displacement, obstruction, pneumothorax and major haemorrhage were the commonest themes.[18]

It is clear that the caseload, physiology, environment, staffing, airway devices and airway pathologies in the critically ill are significantly different to those addressed by existing guidelines.

What does NAP 4 tell us about ICU airways?

In contrast to the enormous literature on anaesthetic airway management, that focusing on airway management in ICU is rather modest. The NAP4 study is therefore important as it identified an increased rate of major airway events on ICU compared with anaesthesia (approximately 50- to 60-fold higher) and a notably worse outcome for patients who experienced these events (61% mortality on ICU vs 14% during anaesthesia).[3] It is important to emphasize that the NAP4 inclusion criteria were only the major complications of airway management: death, brain injury, emergent surgical airway and new (or prolongation of) ICU admission. In total 36 events were reported from ICUs (approximately one major event for every six ICUs in one year) and 18 of the 38 deaths reported to NAP4 occurred in ICU. The NAP4 report was explicit in stating that avoidable airway deaths occurred. The project identified several issues of concern. Compared with the operating theatre setting, ICU was notable for failure to identify high-risk patients, higher rates of night-time events, management by unskilled trainees without a senior clinician, for failure to adhere to a structured guideline or plan of airway management and for a lack of (sometimes standard) equipment. The quality of airway management was judged to be poor during more events on ICU than in anaesthesia: including half of deaths

What should a specific ICU guideline address?

Firstly, when initial airway assessment suggests difficulty, the gold standard technique in anaesthetic practice is awake fibreoptic intubation.[20] This is rarely practical in patients who may already have acquired dependency on non-invasive pressure support, or who are confused, agitated, unstable or unconscious. Current anaesthetic airway guidance does not address either airway assessment or induction, in patients already dependent on advanced oxygenation techniques.

High-flow devices can deliver adequately heated and humidified oxygen at up to 70 L/min flow and may have a number of physiological benefits, including reduction of anatomical dead space, a continuous positive airways pressure (CPAP) effect and delivery of constant fraction of inspired oxygen.[21] In the anaesthetic setting high-flow nasal CPAP has acquired the acronym Transnasal Humidified Rapid-Insufflation Ventilatory Exchange (THRIVE), but this is the same technology as has been widely used for hypoxic critically ill patients for several years. In the elective setting there has recently been great interest in its ability to increase the period of apnoea before hypoxia occurs. This has enabled difficult airway management to be carried out unhurriedly, or even obviated the need to secure the airway during surgery.[22] However its effectiveness in preventing or delaying hypoxia during airway management in the critically ill is unproven. The published literature is limited in extent and quality.[23] Whether THRIVE and/or other methods of potentially prolonging safe apnoea time should be recommended requires careful consideration.[21]

In NAP4 the primary event leading to a major complication on ICU involved difficult or delayed intubation in almost half of the patients. In the ICU setting difficult and delayed intubation is often accompanied by rapid desaturation and instability. It would seem logical to start with the intubation strategy that most readily achieves laryngeal view and first attempt intubation. Videolaryngoscopy has been proposed as a standard of care by some authors but its implementation even in anaesthetic practice is limited, with predominant use as a rescue tool. Studies consistently demonstrate an improved view of the larynx with videolaryngoscopy, but the relationship between this and ease and speed of intubation is more complex.[24 25] Many current international (anaesthesia) guidelines advocate videolaryngoscopy use only when mask ventilation is adequate and an attempt to intubate using direct laryngoscopy has failed. On the one hand it seems logical to make your 'first go' your 'best go' and videolaryngoscopy has the potential to improve laryngeal view.[25] However videolaryngoscopy may slow intubation. This may be of little importance in the elective anaesthetic setting but in hypoxic critically ill patients the few extra seconds taken may contribute to significant hypoxia[24] and potentially worsen outcomes.[26]

The DAS 2015 guidelines place much emphasis on waking the patient when intubation fails. For the critically ill this is often simply not an option. While this may seem a small point, this entirely changes the intubation strategy, as once the patient is anaesthetized the intubator is committed to securing a definitive airway 'come what may'. This simple change of emphasis may have an impact on the choice of anaesthetic induction agent, neuromuscular blocking agent, primary intubation attempts and rescue techniques.

When airway management fails, the final common pathway is the front of neck airway (FONA). The DAS 2015 guidelines make a case for a standardized approach to FONA with the scalpel cricothyroidotomy, as it is judged to be likely the fastest and most reliable method of securing the airway.[7] Things may not be quite so clear-cut in the ICU. A significant number of patients will be managed at some point during their ICU stay with a tracheostomy, and this stoma may be an appropriate rescue route. Intensivists are also likely to be familiar with percutaneous tracheostomies and cricothyroidotomy and these skills may offer additional options when difficulty is encountered. Needle cricothyroidotomy and narrow-bore cannula techniques may be inadequate rescue therapies in the critically ill, as baseline physiological derangements may render the patient dependent on high levels of PEEP, inspired oxygen and inspiratory pressure to ensure adequate oxygenation.

Human factors and team dynamics are always important in management of crises.[3] Guidelines and cognitive aids are an opportunity to codify best practice into a digestible format, for the increasingly complex environment of our critical care units. The multidisciplinary nature of the ICU team provides numerous challenges including the potential interaction between junior and senior colleagues from different base-specialties. The DAS 2015 guidelines recommend a maximum of three attempts at intubation, accepting a fourth attempt by a more experienced colleague. In ICU the senior colleague may not be an airway expert (even if a consultant), expertise may arrive late to the event and appropriate actions may differ compared with the anaesthetic setting.

The development of new guidelines

Current anaesthetic guidelines for management of airway difficulty are not universally applicable to the critical care setting. There have been appropriate calls for guidance specific to critical care and currently no such national guidelines exist.[10 27] As part of the Royal College of Anaesthetists and The Difficult Airway Society's (DAS) response to NAP4, a multidisciplinary working party with representation from the Faculty of Intensive Care Medicine, The Intensive Care Society, DAS, the National Tracheostomy Safety Project, the British Association of Critical Care Nursing and the College is currently drafting such guidance. Further details of the project can be found at www.das.uk.com. We anticipate the guidance will be available in 2017.

Importantly, the lack of guidance may be contributing to morbidity and mortality, highlighted by a recent Coroner's report after an inquest into fatal failed intubation on ICU. The Coroner believed there is a risk of other deaths occurring in similar circumstances, mandating a response from stakeholders under regulation 28 (prevention of future deaths). The aim of new guidelines is to improve the safety of airway management in the critically ill, as it is clear that we cannot continue to manage the airways of elective day case patients and those at the margins of survival in exactly the same manner.

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Seeing is believing: getting the best out of videolaryngoscopy

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Almost half of all incidents reported to the 4th National Audit Project (NAP4) of the Royal College of Anaesthetists and the Difficult Airway Society (DAS) described airway complications that followed primary problems with intubation, including failed tracheal intubation, delayed tracheal intubation, and 'can't intubate can't oxygenate' (CICO) situations.[1] In addition, considerably more than half of the incidents reported to NAP4 involved problems with intubation as the airway incident progressed.[1] The recently published DAS 2015 guidelines emphasize the importance of the first attempt at laryngoscopy, with the aim of Plan A being to 'maximize the likelihood of successful intubation at first attempt, or failing that, to limit the number and duration of attempts at laryngoscopy, to prevent airway trauma and progression to a CICO situation.'[2] It is recognized that a suboptimal attempt at laryngoscopy is a 'wasted attempt' and that, if intubation fails, the chance of success declines with each subsequent attempt at laryngoscopy.[2–4] The importance of first-pass success is arguably even greater in the critically ill patient, when multiple attempts at intubation lead to high rates of severe hypoxia and other life-threatening (or life-ending) complications.[5]

Benefits of videolaryngoscopy

Videolaryngoscopy is undoubtedly one of the major advances in practical anaesthesia in recent years. At present, the main challenges are to determine to what extent it should penetrate routine clinical practice and to determine which devices are best. The progression from standard Macintosh laryngoscopes to videolaryngoscopes has been likened to the advance from standard mobile cell phones to smart phones.[6] Several editorialists have called for videolaryngoscopy to be a first-line technique for airway management.[7–10] Importantly, the role of videolaryngoscopy in difficult intubation has recently been recognized in the DAS 2015 guidelines, which recommend that all anaesthetists are trained in videolaryngoscopy and that all anaesthetists have immediate access to a videolaryngoscope at all times.[2] Videolaryngoscopy has been recommended for intubating obese patients,[3 11 12] a group known to have a higher risk of complications associated with airway management.[1 2] Beyond anaesthesia, predictions have been made that videolaryngoscopy will dominate the field of emergency airway management in the future.[4 7 13] It seems that cost is the main consideration holding back the tide.[7 9]

There are many reasons for such enthusiasm. Firstly, there are numerous technical benefits. Videolaryngoscopy gives the user a better view of the larynx than with a standard Macintosh laryngoscope (direct laryngoscopy).[2 6–8 12] This improved laryngeal view is the result of two factors: for videolaryngoscopes with Macintosh-shaped blades, a camera on the distal end of the blade gives an increased field of view compared with direct laryngoscopy, whereas for videolaryngoscopes with extra-curved blades, this increased field of view is augmented by the capacity to 'see around the corner' and gain a view of structures that are beyond the reach of Macintosh-style blades.[6] This improved view of the larynx is seen even with only minimal head and neck manipulation.[7 12]Appropriately chosen videolaryngoscopes are therefore beneficial for the management of both anticipated and unanticipated difficult laryngoscopy.[7 14 15] The force required when intubating with a videolaryngoscope is less than that required for direct laryngoscopy, resulting in less risk of trauma to soft tissues and teeth,[14 16–19] and a reduced incidence of sore throat.[18 19] Several videolaryngoscopes have a higher rate of successful intubation when used as a rescue device when direct laryngoscopy fails.[2 20–22] As most difficult intubations are not anticipated,[14 15] first-line use of videolaryngoscopy not only reduces the risk of difficulty, but, when this occurs, eliminates the need for the intubator to swap to another device when time and oxygenation are critical. The number of attempts at laryngoscopy can be kept to a minimum, and it is highly likely that unanticipated difficult intubation would be less frequent if videolaryngoscopes were used as a first-line technique.[7]

Secondly, there are significant training advantages associated with using videolaryngoscopes, though perhaps restricted to videolaryngoscopes that have a remote screen rather than one attached to the laryngoscope handle. When the trainer can observe the larynx on a screen while the trainee performs laryngoscopy, the trainer can help the trainee to optimize the blade position and advise the trainee on where to place the tracheal

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Strategies to improve first attempt success at intubation in critically ill patients

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Abstract

Tracheal intubation in critically ill patients is a high-risk procedure. The risk of complications increases with repeated or prolonged attempts, making expedient first attempt success the goal for airway management in these patients. Patient-related factors often make visualization of the airway and placement of the tracheal tube difficult. Physiologic derangements reduce the patient's tolerance for repeated or prolonged attempts at laryngoscopy and, as a result, hypoxaemia and haemodynamic deterioration are common complications. Operator-related factors such as experience, device selection, and pharmacologic choices affect the odds of a successful intubation on the first attempt. This review will discuss the 'difficult airway' in critically ill patients and highlight recent advances in airway management that have been shown to improve first attempt success and decrease adverse events associated with the intubation of critically ill patients.

Key words: airway management; critical care; emergency department; emergency medicine; intensive care; intubation; laryngoscopy; prehospital

Editor's key points

Airway management in critically ill patients is high risk as a result of anatomic and physiologic characteristics that increase the risk of complications. Complications include hypoxaemia, aspiration of gastric contents, haemodynamic deterioration, hypoxic brain injury, cardiopulmonary arrest and death. One or more complications occur in 22–54% of all intubations performed in critically ill patients, making emergent intubation one of the highest risk procedures a patient may require.[1–5]

The 4th National Audit Project (NAP4) report of the Royal College of Anaesthetists and the Difficult Airway Society identified several deficiencies that increased the risk of adverse outcomes related to emergent airway management.[6] Opportunities identified for improvement include pre-intubation assessment, planning for the initial attempt and identification of back-up plans, and availability and use back-up devices and personnel. Publication of the NAP4 report has invigorated focus on improving the safety of emergency airway management. This review will discuss the 'difficult airway' in critically ill patients and present evidence-based strategies for maximizing first attempt success with airway management in the intensive care unit. The evidence was obtained through relevant search terms in PubMed and articles were evaluated for relevance, applicability and further pertinent references.

The difficult airway problem and the importance of first attempt success

Critically ill patients often have full stomachs and compromised physiology such that multiple or prolonged attempts are poorly tolerated and result in an increased risk of complications. Griesdale and colleagues[2] reported an overall complication rate of 39% in the intensive care unit, with 13% of all intubations requiring three or more attempts and 10% requiring 10 or more min.

Mort[7] found that when aspiration or hypoxaemia occurs during emergency intubation, patients are 22 times and four times more likely, respectively, to have a cardiac arrest.[7] Patients that had a cardiac arrest during intubation commonly had an oesophageal intubation, which increases the incidence of hypoxaemia and aspiration and increased the risk of death seven-fold. These complications occur more frequently when repeated attempts are required. When more than two attempts were required during emergency intubation, serious complications increased: aspiration of gastric contents (22% *vs* 2%), hypoxaemia (70% *vs* 12%), and cardiac arrest (11% *vs* 1%).[1] More recent data from Sakles and colleagues[8] in the emergency department shows that the risk of adverse events increases with each successive attempt, increasing from 14 to 47% when a second attempt is required. These data suggest that the goal of emergency intubation in the critically ill should be first attempt success.

First attempt success is affected by both patient-related and operator-related factors. Patient-related factors include anatomic features that make visualization of the glottic inlet or the ability to pass a tracheal tube difficult,[9–12] and physiologic factors that limit the duration of the laryngoscopic attempt such as hypoxaemia or haemodynamic instability.[13] Operator-related factors include the experience of the operator,[14–17] device selection,[18–21] and pharmacologic agents used to facilitate the procedure.[22–24] Consequently, any tool that allows the operator to predict the potential difficulty associated with an intubation could be useful for the operator to plan for obviating those potential difficulties.

Difficult intubations are frequently encountered in the emergency department, intensive care unit, and prehospital settings and have been reported to range between 8-13%.[2 3 16 25 26] Conventionally, the 'difficult airway' has been defined as an intubation that requires >2 attempts or 10 min to secure placement of an tracheal tube.[3 16 27] There are several limitations when applying this definition to critically ill patients. First, methods and rules developed to predict the difficult airway have only modest performance.[28–30] Second, utilizing this definition may predict a potentially difficult airway (i.e. >2 attempts), but does not differentiate patients that are at risk of requiring more than one attempt. Many of the patient and operator-related factors described above, and environmental factors such as limited space, poor lighting, and suboptimal bed characteristics that limit the ability to properly position or access the airway, are not included in these prediction models. Lastly, the patient's physiologic derangements may cause difficulty in maintaining oxygenation during the intubation attempt, creating a 'difficult airway' even in the absence of predicted anatomic difficulty.[13 31]

Several methods of pre-intubation assessment aimed at predicting the difficult airway have been developed, all of which focus on the anatomic features that make visualization of the glottic inlet difficult.[11 28 32] These tests have been shown to be difficult to perform in many patients requiring emergency intubation.[33 34] Recently, the MACOCHA score was developed to identify the potentially difficult airway in the intensive care unit. This score considers both patient-related factors pertaining to anatomic difficulty, physiology, and operator-related factors.[32] The components included are: Mallampati score of III or IV, obstructive sleep apnoea, cervical immobility, limited mouth opening, coma, severe hypoxaemia, and non-anaesthetist operators. This seven-item score differentiates difficult from routine intubations with a sensitivity of 73%.[32] Unfortunately, the MACOCHA score does not adequately predict first attempt success, and has not been validated for video laryngoscopy. De Jong and colleagues found that when considering intubations predicted to be difficult by the MACOCHA score, only 4% of intubations performed with the C-MAC video laryngoscope were difficult.[35] Consequently, given the poor reliability of difficult airway *predictors* and difficulty performing pre-intubation assessments properly, attempts to maximize first attempt success should be based on the *characteristics* that make laryngoscopy or placement of a tracheal tube potentially challenging rather than pre-intubation predictors of a 'difficult intubation' that will require >2 attempts or more than 10 min.[36]

Maximizing first attempt success

Preoxygenation

Patients undergoing elective surgeries typically have adequate cardiopulmonary optimization before intubation and are usually able to tolerate short periods of apnoea. This degree of optimization may not be possible for critically ill patients, who frequently require intubation unexpectedly with little time for assessment and preparation. In addition, critically ill patients usually have significant physiologic derangements adding another layer of difficulty to airway management. The lack of time, high oxygen requirement, shunt physiology, and lack of patient cooperation all complicate adequate preparation.[3] These factors can increase the risk of complications during intubation. Oxygen desaturation is the most common complication, occurring in 19–70% of intubations.[1–3 37–42] Oxygen desaturation is also likely the most common reason for an aborted first attempt at intubation, both of which increase the risk of further complications. Therefore, optimization of preoxygenation is of particular interest to prolong time to desaturation and thus improve the likelihood of first attempt success.[43]

The process of preoxygenation is used to replace the nitrogen rich ambient air in the alveoli with oxygen, which is then available for uptake during periods of induced apnoea. In healthy patients, this may be achieved by 3–5 min of tidal breathing or eight vital capacity breaths from a tight fitting non-rebreather mask delivering 100% oxygen.[44–47] However, recent data from Groombridge and colleagues[48] showed that in healthy volunteers, a non-rebreather face mask is much less effective in achieving an adequate end tidal O2 than both bag-valve mask and a closed anaesthetic circuit. Hayes-Bradley[49] recently demonstrated that the addition of supplemental oxygen via a nasal cannula in the presence of mask leaks may be helpful in improving end tidal O2. In patients who are critically ill, the effectiveness of and optimal strategy for preoxygenation is not clear. Mort [50] reported that providing 100% oxygen for 4 min increased the partial pressure of arterial oxygen by 6.7 kPa in only 19% of patients, and extending the period of preoxygenation had little impact.[51] In addition to shunt physiology and complicating comorbidities such as obesity, preoxygenation in critically ill patients may be less efficient secondary to the rigid mask typically used, which allows mixing of ambient air causing a decrease in the effective fraction of inspired oxygen. This effect likely worsens with high min ventilation requirements as a greater proportion room air is entrained.

In stable patients undergoing general anaesthesia, a 20-degree elevation of the head has been shown to improve pre-oxygenation and extend safe apnoea time.[52] Non-invasive positive pressure ventilation has also been used to improve pre-oxygenation before intubation in patients with obesity and shunt physiology.[53 54] Baillard and colleagues[53] reported that 3 min of preoxygenation with non-invasive positive pressure ventilation improved preintubation saturation and reduced desaturation to <80% with intubation from 46 to 7% compared with using a nonrebreather mask for 3 min. A supraglottic airway may also be useful for pre-oxygenation before an intubation attempt, in patients requiring higher airway pressures, or that cannot tolerate the non-invasive positive pressure ventilation mask.[55] In patients with severe hypoxaemia and inability to adequately preoxygenate with non-invasive positive pressure ventilation, Delayed Sequence Intubation in which procedural sedation is performed to facilitate mask tolerance and improve preoxygenation before laryngoscopy may be useful.[56] Preoxygenation with positive pressure on the ventilator via a tight fitting facemask, with the addition of supplemental oxygen delivered during the intubation through a nasal cannula may attenuate desaturation in patients with severe hypoxaemia.[57]

High-flow nasal cannulas (HFNC) capable of providing heated, humidified flows of oxygen up to 70 litres per min (lpm) have been compared with standard methods of preoxygenation with mixed results.[58–60] In a pre-post intervention study by Miguel-Montanes and colleagues[58], oxygen delivered at 60 lpm via HFNC for preoxygenation and kept in place during the intubation procedure (apnoeic oxygenation) reduced the incidence of desaturation from 14 to 2% compared with non-rebreather facemask preoxygenation. However, two randomized controlled trials on apnoeic oxygenation have shown no benefit during emergency intubation. Semler[59] and colleagues evaluated 15 lpm through a high-flow nasal cannula compared with usual care and found no difference in the median lowest arterial saturation (92% *vs* 90%) or in the incidence of desaturation to <90% (45% *vs* 47%). Vourc'h and colleagues[60] compared 60 lpm by HFNC for preoxygenation and apnoeic oxygenation to facemask preoxygenation and found no difference in incidence or severity of desaturation. A recent study from Sakles and colleagues[61] in the emergency department has shown an association between apnoeic oxygenation and a higher first attempt success without hypoxemia.

Maintenance of oxygenation

During apnoeic oxygenation, supplemental oxygen provided to the nasopharynx via a nasal cannula moves to the alveoli by mass diffusion, driven by a gradient caused by ongoing oxygen uptake from the alveoli. This phenomenon has been known for close to a century, and while it does not provide ventilation, apnoeic oxygenation provided through a high-flow nasal cannula during laryngoscopy may decrease desaturation during intubation.[62 63] Apneic oxygenation provided by high flow nasal cannula has also been shown to be useful when awake fiberoptic intubation is required for an anticipated difficult airway.[64] The effectiveness of apnoeic oxygenation in the critically ill patient may be limited because of the presence of disease processes causing a physiologic shunt, which cannot be completely overcome by increased oxygen concentrations. Continuous positive pressure using a nasal non-invasive positive pressure ventilation mask during the intubation may be useful for maintaining alveolar recruitment during intubation, in patients with shunt physiology.[65] More studies are needed to evaluate the role of these modalities to augment oxygenation during intubation, however they represent low cost, low-risk interventions that may improve the safety of emergency intubation.

Haemodynamic optimization and drug selection

Physiologic difficulties such as hypoxaemia or haemodynamic instability may not inhibit the ability to visualize the vocal cords or pass a tracheal tube, *per se*, but they should be accounted for and may alter the intubation plan. While hypoxaemia makes preoxygenation challenging and limits the duration of safe apnoea, haemodynamic instability is an independent predictor of death after intubation.[66] Post-intubation hypotension is common, reported in nearly half of patients intubated in the intensive care unit,[67] with cardiovascular collapse occurring in 30% of patients.[66–68] In addition to the risk of immediate cardiopulmonary arrest and death after intubation, peri-intubation haemodynamic instability leads to longer intensive care unit stays and increased in-hospital mortality.[66 69–72] Green and colleagues[67] reported an overall incidence of post-intubation hypotension of 46%, which doubled the odds of a composite endpoint of mortality, intensive care unit length of stay >14 days, mechanical ventilation >7 days and renal replacement therapy. When patients required vasopressors within 60 min of intubation, there were even higher odds of in-hospital death (3.84; 95% CI: 1.31–11.57) and a mortality of 38%.[73] Predicting those who will develop post-intubation hypotension has proved difficult. Similar to data from the emergency department,[74] a pre-intubation shock index (heart rate/systolic blood pressure) >0.90 had an odds ratio of 3.17 (95% CI 1.36–7.73) of developing post-intubation hypotension.[75] While pre-intubation shock index may be useful, still one-third of patients with a normal shock index will develop post-intubation hypotension. Based on these data, aggressive resuscitation with volume and vasopressors if necessary should be performed in critically ill patients concurrently with preoxygenation to improve the safety of emergency intubations.

While appropriate fluid resuscitation is the mainstay of preventing post intubation hypotension, the proper selection of pharmacological adjuncts for airway management is also important to prevent cardiovascular collapse. Medications used in airway management should facilitate optimal conditions to place the tracheal tube, while ensuring patient comfort and minimizing adverse haemodynamic effects. Lower doses may be required in critically ill patients based on the haemodynamic profile of the patient, although under-dosing also risks inadequate effects and adverse outcomes such as patient discomfort.

Several induction agents are available for intubation. Haemodynamically neutral induction agents such as etomidate are preferred, or reduced doses of benzodiazepines or propofol, which have properties that lead to myocardial depression and a decrease in systemic vascular resistance.[76–78] While some have raised concerns about transient adrenal insufficiency in patients with sepsis, data are conflicting and convincing evidence of harm is lacking.[79 80] Ketamine is an attractive alternative because of its sympathomimetic effects, which can help maintain blood pressure during intubation. Ketamine has been shown to have no higher rate of complications when compared with etomidate and, unlike other induction agents, it exhibits both amnestic and analgesic properties.[81 82] Ketamine is also valuable in that it allows for the maintenance of spontaneous ventilation by inducing a unique state of dissociative anaesthesia and, as a result, can be useful in facilitating 'awake' intubation techniques. Specific risks associated with ketamine include laryngospasm, myocardial depression and increased airway secretions. Dexmedetomidine, an alpha-2 agonist, may be useful in some patients. Although not an induction agent, the maintenance of spontaneous respiration makes dexmedetomidine an excellent option for awake fiberoptic intubations.

The use of a neuromuscular blocking agents, either in rapid sequence or delayed sequence after the sedative agent, has been shown to improve first attempt success regardless of the choice of induction agent (etomidate *vs* ketamine), neuromuscular blocking agents (succinylcholine *vs* rocuronium) or route of administration (i.v. *vs* intraosseous).[22 56 83–85] Wilcox and colleagues[23] showed that the use of a neuromuscular blocking agent to facilitate intubation in two academic intensive care units was associated with a 7% decrease in hypoxaemia, 5% decrease in complications, and significantly improved intubating conditions, including a 7% increase in first attempt success. Mosier and colleagues[22] reported an odds ratio of first attempt success of 2.37 (95% CI: 1.36–4.88) and no increase in procedurally-related complications, when neuromuscular blocking agents were used in a propensity-matched analysis of 709 consecutive intensive care unit intubations. Neuromuscular blocking agents not only improve grade of view and overall intubating conditions but they also decrease vomiting, especially when combined with a head-up or ramped position.

Pharmacologic adjuncts are available to minimize adverse events with induction although supporting data are limited. Lidocaine, can be given topically to blunt the sympathetic response to laryngoscopy or facilitate the ability to perform an 'awake' intubation in the spontaneously breathing patient. I.V. lidocaine may be used in patients where a raised intracranial pressure (ICP) is a concern to limit spikes in ICP during laryngoscopy. Opiate medications have a similar 'blunting' effect but also have a sedating effect. See Table 1 for a summary of commonly used pharmacologic agents for airway management.

Device selection

A large variety of devices are available for airway management. Broadly, the devices may be categorized as direct laryngoscopes, indirect laryngoscopes (optical or video laryngoscopes), flexible fiberoptic devices and supraglottic devices. Laryngoscopy has traditionally been performed with a direct laryngoscope, using either a Macintosh or Miller blade. When using a direct laryngoscope, the tissues of the upper airway must be compressed and displaced to provide the operator a view of the glottic inlet. In the last 15 years, video laryngoscopes have become widely available and are currently available in most academic training programs.[86] There are two main categories of video laryngoscopes: standard geometry Macintosh-type curved blade devices, and hyperangulated devices. The hyperangulated devices can be further broken down into those without a tube-guiding channel and those with a channel. The benefit of video laryngoscopy is that the view of the glottic inlet is projected onto a video screen from a camera attached to the undersurface of the blade. This obviates the need to displace the tissues of the upper airway and allows the operator to effectively 'see around the corner'.

Video laryngoscopy has been shown to increase first attempt success in the emergency department, intensive care unit, and pre-hospital setting, including patients with difficult airway predictors and those with a failed first attempt.[18 20 21 87–92] Two randomized controlled-trials were recently published with conflicting results. Griesdale and colleagues[91] reported improved glottic visualization with video laryngoscopy but no difference in first attempt success (40% *vs* 35%), in a pilot study performed in a mixed medical and surgical intensive care unit. A statistically significant increase in first attempt success (74% *vs* 40%) was shown in a second trial, however, using video laryngoscopy in a medical intensive care unit.[90] Both studies excluded patients with anticipated difficult airways, used only one video laryngoscope (GlideScope), and used neuromuscular blocking agents in either all[91] or none[90] of the patients included. A meta-analysis by De Jong and colleagues[18] in 2014 showed first attempt success was twice as likely to occur with the use of a video laryngoscope. The largest comparison of video laryngoscopy to direct laryngoscopy in the intensive care unit to date is a propensity-matched analysis by Hypes and colleagues[19] that demonstrates higher odds of first attempt success (2.81, 95%CI 2.27–3.59) and a lower complication rate when a video laryngoscope was used. Most of the

Table 1 Pharmacologic agents commonly used for airway management. Abbreviations: GABA, Gamma-Aminobutyric Acid; RAS, Reticular Activating System; Ach, Acetylcholine; Na, sodium

Drug	Dose in mg kg^{-1}	Site/Mechanism of Action	Onset of Action (s)	Duration of Action (min)	Comments
Sedative Agents					
Etomidate	0.3	GABA in RAS	15–45	3–12	–Haemodynamically neutral
Propofol	1–3	GABA	15–45	3–5	–Myocardial depressant-Hypotension
Ketamine	1–2	GABA, opiate, nicotinic, vascular nitric oxide	<60	10–20	–Direct myocardial depressant but indirect sympathomimetic
Thiopental	3–5	GABA in RAS	5–30	5–10	–Negative inotrope-Frequently causes hypotension
Midazolam	0.1–0.3	GABA in RAS	30–60	15–30	–Frequently causes hypotension
Dexmedetomidine	0.5–1 mcg kg^{-1}	Alpha-2 agonist	10–15 min	~120	–Blunts laryngeal response-Maintains spontaneous respiration
Neuromuscular Blocking Agents					
Succinylcholine	1–2	Nicotinic Ach receptors	30–60	~10	–Only Depolarizing agent
Rocuronium	0.9–1.2	Ach Receptor Antagonist	60–90	~160	–Prolonged duration of action
Adjuncts					
Lidocaine	1.5–2.5	Ionic Na channel	45–90	10–20	–Local, topical, and i.v. use
Opiates	Variable	Mu receptors	120–180	30–60	–Hypotension because of blunting of sympathetic drive in critically ill patients
Benzodiazepines	Variable	GABA	120–180	30–60	–Hypotension because of blunting of sympathetic drive in critically ill patients, amnesia

Table 2 Strategies to optimize first attempt success and improve safety of emergent intubations

Strategy	Method	Comments
Pre-intubation		
Preoxygenation	1. >20 degrees head-up position, and 2. 3–5 min of 100% oxygen with tight fitting facemask, or HFNC, or 3. Non-invasive positive pressure ventilation.	non-invasive positive pressure ventilation is preferred for preoxygenation in patients with shunt physiology.
Haemodynamic optimization	1. Bedside haemodynamic assessment, and 2. Fluid resuscitation as necessary, and 3. Continuous vasopressor infusion for refractory hypotension despite fluid resuscitation.	1. Shock index >0.9 has higher odds of developing post-intubation hypotension. 2. Bedside ultrasound can provide a rapid, accurate haemodynamic profile.
Resource management	1. Assess potential difficulty, and 2. Verbalize 'Plan A,' 'Plan B', etc., and 3. Prepare all necessary equipment and backup devices, and 4. Position patient, and 5. Assign individualized roles for team members, and 6. Prepare post-intubation sedation and analgesia.	1. Potential difficulty includes difficult anatomy and difficult physiology that limit ability to perform laryngoscopy, mask ventilation, supraglottic placement, or surgical airway.
Human factors	1. Presence of two operators with agreement on approach.	
During Intubation		
Maintenance of oxygenation	1. Apnoeic oxygenation may prolong safe apnoea time.	1. Apnoeic oxygenation efficacy limited with shunt physiology. Nasal CPAP during intubation may be more beneficial in these patients.
Device selection	1. Device selection based on difficulty assessment. 2. Video laryngoscopy improves odds of first attempt success.	1. If fiberoptic intubation is to be performed, combination techniques such as combined fiberoptic device-video laryngoscope or fiberoptic devices-supraglottic device may be useful.
Medication selection	1. Haemodynamically neutral sedative such as etomidate or ketamine, and 2. Neuromuscular blocking agent when oral laryngoscopy is being performed.	
Programmatic Considerations		
Multidisciplinary approach	1. Combined training, didactics, simulations, etc. to improve performance of all specialists rather than limit to one specialty.	Difficult airway 'teams' may be useful in some institutions.
Training programs	1. Simulation-based curricula to advance skills in identification and management of the difficult airway.	
Human Factors	1. Education and training on difficult airway algorithms, and 2. Use of cognitive aids during intubation to improve recall and performance.	
Resource Management	1. Adequate and readily available equipment is necessary.	1. Difficult airway carts with all necessary equipment should be available in each ICU.

literature on video laryngoscopy in critically ill patients involves the C-MAC (Karl Storz, Tuttlingen, Germany) and GlideScope (Verathon, Bothell, WA). These two devices have been shown to be of equal efficacy.[93] When using a hyperangulated video laryngoscope, the use of a rigid stylet is associated with a higher first pass success.[94]

Video laryngoscopes have also been shown to improve first attempt success in logistically challenging situations, such as in patients with in-hospital cardiac arrest, or when performed by novice physicians.[95 96] While direct laryngoscopy is an important skill to maintain for all practitioners that frequently perform intubations, acquiring this skill is difficult, with close to 50 intubations required for an operator to become competent with direct laryngoscopy in uncomplicated patients.[97 98] The learning curve for video laryngoscopy appears much more favorable.[99] An additional benefit of video laryngoscopes is that they play a role in improving human factors associated with airway management. Video laryngoscopes improve training for novices by allowing real-time instruction and provides an avenue for documentation of airway anatomy for future airway management, both of which can improve patient safety and some authors advocate for video laryngoscopy to be the standard of care.[100–102] Based on the available evidence, video laryngoscopy should be considered as the initial device especially in patients with difficult airway characteristics, to maximize the likelihood of first attempt success.

A point of emphasis in the NAP4 report was the lack of availability and use of flexible fiberoptic devices for intubation in patients with challenging airways.[6] Patients with potentially anatomically challenging airways and in whom bag-valve mask ventilation is likely to be difficult or inadequate, may be candidates for an 'awake' intubation using sedation and topical anaesthesia only and a flexible fiberoptic device or video laryngoscope. In operators with limited experience with flexible fiberoptic devices, a combined technique using a flexible fiberoptic device with a laryngoscope can be helpful.[103]

Human factors: training, algorithms, and bundles

While patient-related factors in critically ill patients, such as altered physiology, present a higher risk of complications during airway management, operator-related factors should be addressed and planned for as well. Intubations in the ICU may be required at any time of day with little time for preparation and thus are often performed by less experienced practitioners. This has sparked controversy over who should perform intubations in the intensive care unit, as interest grows in improving procedural safety.[2 14 16 17 25 104] While anaesthetists may perform more intubations than other specialists, experience, training, comfort and availability for emergent 'out-of-operating theatre' airway management may be variable. Airway management training is an integral part of the training of all specialties that care for critically ill patients and improving training and practice patterns for all specialists perhaps serves better than limiting the skill to one specialty.

Simulation-based training experiences, algorithms, and bundles designed to address this problem have produced varying degrees of success. Jaber and colleagues[105] reported that implementation of an airway management bundle, which included preoxygenation with non-invasive positive pressure ventilation, use of a neuromuscular blocking agent, and fluid loading before intubation decreased the incidence of minor complications by 12% and life-threatening complications by 13%. A quality improvement program for pulmonary and critical care trainees that included a simulation-based training program, crew resource management techniques, a team approach to intubation with assigned roles, and an intubation checklist showed only modest results with a 62% first attempt success rate, 20% of intubations requiring three or more attempts, and an 11% oesophageal intubation rate, although there was no comparison group in this descriptive analysis.[106] Mosier and colleagues[36] recently published a three-year airway management curriculum experience that included an intensive simulation-based program with gradually increasing difficulty focusing on the identification of and approach to the potentially difficult airway. This curriculum improved the odds of first attempt success and decreased complications in the intensive care unit, with an overall first attempt success >80% and nearly 90% when a video laryngoscope was used. Table 2 summarizes the best available evidence to optimize the likelihood of first attempt success and decrease complications for intensive care unit intubations.

The ASA, the Canadian Airway Focus Group, and the Difficult Airway Society have developed excellent guidelines for management of the difficult airway; however, their performance in the emergency department, intensive care unit and pre-hospital is unknown.[27 107–109] Recently, two approaches to airway management in the critically ill have been developed, one as a cognitive aid[110] and one as a strategic algorithm[36] to maintain adequate oxygenation, in patients in the event of a first attempt failure. Further research is needed in this area to guide airway management for the critically ill patient.

Conclusion

Critically ill patients requiring intubation are challenging because of patient- and operator-related factors that make intubation high-risk for serious complications. First attempt success should be the goal to reduce this risk, which increases with each attempt. Strategies to achieve first attempt success include adequate preoxygenation, apnoeic oxygenation, haemodynamic optimization, and appropriate device and medication selection. Inclusive training programs, algorithms, and cognitive aids should be implemented to improve operator-related factors with airway management. Individualized approaches to airway management for each patient's unique characteristics will optimize the likelihood of first attempt success while maintaining adequate oxygenation and ventilation. Several advances have been made in emergency airway management since the NAP4 report, yet continued research is needed to further address improving identification of high-risk critically ill patients, assessing optimal device and drug selection, and optimizing tools to improve first attempt success and reduce complications.

Authors' contributions

Study design/planning: B.S.N., J.M., C.D.H., J.C.S., J.M.M.
Study conduct: B.S.N., J.M., C.D.H., J.C.S., J.M.M.
Writing paper: B.S.N., J.M., C.D.H., J.C.S., J.M.M.
Revising paper: all authors

Declaration of interest

J.C.S. serves on the scientific advisory board for Verathon.

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The great airway debate: is the scalpel mightier than the cannula?

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Although anaesthetists are experts at managing a patient with airway obstruction, most have never had to perform emergency front-of-neck access (FONA) procedures. The need to resort to an emergency FONA procedure is extremely rare and may occur only once in an anaesthetist's professional lifetime.[1] Despite the low incidence of a cannot intubate, cannot oxygenate (CICO) crisis, the outcome accounts for a large proportion of airway-related deaths and is often associated with very significant morbidity.[2 3]

There is ongoing debate about whether a scalpel or a cannula is the best device to access the airway when performing a FONA procedure for CICO.[4] Regardless of this debate, most anaesthestists would agree with the criteria for an ideal FONA technique for CICO: it should be a straightforward technique that is quick to perform, with a high success rate; it should be easy to master, with only a few steps; and it should protect against aspiration and allow adequate ventilation, regardless of upper airway obstruction.[5] These criteria are met only with a scalpel technique.

The 2015 Difficult Airway Society guideline for management of an unanticipated difficult intubation has recommended a scalpel–bougie FONA procedure.[6] This recommendation is evidence based and consistent with the criteria of an ideal FONA technique. There is no clinical evidence to support cannula cricothyroidotomy in preference to a scalpel technique. Furthermore, there is no evidence that a commercial large-bore cricothyroidotomy set is superior to a scalpel–tube technique.

A scalpel–bougie technique uses equipment familiar to every anaesthetist. It is suitable for a simple standard operating procedure, which can be learned easily and used in a CICO crisis by any practising anaesthetist. Use of a scalpel, bougie, cuffed tracheal tube, and self-inflating ventilation bag permits a rapid solution to a CICO crisis, providing definitive FONA, which may be important if urgent surgery is required. The technique includes a tracheal tube, which enables safe, secure ventilation even in the presence of regurgitation or upper airway obstruction. Furthermore, a scalpel is the appropriate instrument for an open procedure when neck anatomy is impalpable percutaneously.

A recent systematic review of transtracheal jet ventilation (TTJV) by Duggan and colleagues[7] highlighted four important issues concerning emergency airway management. First, the ventilation component of FONA using TTJV is associated with device failure, severe morbidity, and mortality. Unfortunately, the importance of ventilation after FONA is often ignored during the debate about scalpel *vs* cannula. Second, there is wide variability in TTJV technique. Third, there is a high failure rate to identify the cricothyroid membrane correctly by clinical means alone. Fourth, morbidity associated with TTJV during an emergency CICO crisis is significantly higher than that occurring during elective or non-emergency use of TTJV.

Although it may seem simpler and less daunting for anaesthetists to insert a cannula into the airway rather than placing a scalpel, evidence shows that the cannula option has a high failure rate in the clinical context. Furthermore, the potential ventilation techniques following emergency cannula cricothyroidotomy can be dangerous in the case of TTJV and three-way taps; and inadequate in the case of ventilation bags attached to the cannula.[7–9] Other options remain untested in the emergency setting; there are no clinical reports of successful emergency use of the Enk oxygen flow modulator or the Rapid-O2 device. Both of these devices are T-piece variants with equivalent side-port diameter. A small volume of forward gas flow continues during the expiratory phase when the side-port is open, aggravating the risk of barotrauma in the presence of upper airway obstruction.[10] The Ventrain shows promise as a mode of cannula ventilation. As yet, this device lacks clinical published results to support its use in FONA emergencies, but unpublished case reports do confirm the efficacy of the Ventrain in this scenario (personal communication from Professor Dietmar Enk). Any FONA option that relies solely on an uncuffed cannula affords no protection against aspiration and provides only a precarious temporary airway.[11] All of these options also carry a risk of causing barotrauma in the presence of operator error and significant upper airway obstruction.

The second matter put forward by Duggan and colleagues[7] concerned a lack of standardization of the TTJV technique. Cannula type and size, oxygen source, driving pressure, and jetting frequency all varied significantly. This indicates a lack of consistent training, confusion about optimal operation of the device, and potential dysfunction during a crisis. Using a complex device or technique during a stressful event, such as CICO, when motor skills and cognitive processing can be impaired, will lead to frequent difficulties.

The third finding confirms previous studies that have shown the difficulty of successfully identifying the cricothyroid membrane by clinical means alone.[1 12] The outcome of an emergency FONA is likely to be improved by preparation before induction of anaesthesia in all patients.[13] Identification of the trachea and the cricothyroid membrane should be an intrinsic part of any airway evaluation.[14] In many patients, this can be done by inspection, palpation, or both.[12] In the remaining patients, confirmation of anatomical landmarks can be aided by adding ultrasound-guided identification.[15] In patients for whom percutaneous access to the cricothyroid membrane might be difficult or impossible, the airway management strategy can be modified accordingly; for example, by performing an awake intubation.

The fourth finding concerned the significant difference in outcome when TTJV was used in a CICO emergency compared with elective or non-emergency use. It was found that nearly all problems associated with TTJV occur during the stressful event of a CICO emergency. Even experienced users of this technique demonstrate technical problems when exposed to stress. Other seemingly simple procedures, such as percutaneous identification of the cricothyroid membrane, reveal poor success rates of 30–40% during relatively low levels of stress. This problem highlights the difficulty of translating laboratory CICO performance using manikins, animals, or cadavers to a real clinical crisis. Performance in an unstressed environment is different from performance during a real CICO situation.

Timmermann and colleagues[4] make an important point in their defence of cannula techniques. A major determinant of outcome in severe hypoxaemic events is the decision-making that leads to decisive use of a rescue technique. It may be that anaesthetists are more comfortable with cannula techniques, although there is little evidence to support this concept. However, the high failure rates of cannula techniques and high success of scalpel techniques mean that we are obliged to address decision-making in emergency anaesthetic training to ensure that the effective intervention is carried out when indicated. The concept that an unreliable and ineffective intervention should be carried out because it is more comfortable for operators cannot be supported.[16]

Performance during stressful events has been studied for more than a century, looking at skill acquisition, fine motor control, and cognition, and their relationship to muscle size, severity of stress, task difficulty, and increasing heart rate.[17] Numerous studies have confirmed that maintenance of fine motor skills requiring accuracy and cognition demand conditions of low stress; the threading of, for example, a Seldinger wire through a Melker cricothyroidotomy set may well require such accuracy and cognition. It was found that the performance of subjects' fine motor skills deteriorated with heart rates >115 beats min^{-1}, and complex motor skills began to deteriorate above 145 beats min^{-1}. Extreme stress is associated with cognitive deterioration, perceptual narrowing, and a state of hypervigilance. At this level of stress, when heart rates can accelerate above 175 beats min^{-1}, subjects display irrational behaviour, decreased reaction times, and may freeze in place (hypervigilance). These behaviours can be identified in practitioners involved in numerous reported airway management catastrophes.

An understanding of the physiological response to stressful situations has allowed other professions to adapt their behaviour and training to minimize the impact of stress. As it is recognized that any stressful situation is likely to increase a subject's heart rate >145 beats min^{-1}, training is designed, whenever possible, to focus on gross motor skills rather than fine motor skills. Breath control and visualization techniques are practised by athletes and soldiers to control heart rate. Rehearsing performance outside the static atmosphere of a classroom helps to develop situational confidence. By training in simulated conditions of stress, a student's reaction and response times are dramatically reduced.[17]

The CICO situation is so rare in anaesthesia that there is a shortage of clinical evidence specific to the specialty. Critical events are rarely reported, and conclusions have inevitably been drawn from anecdotal human evidence, expert opinion, and non-human data, such as animal laboratories. Large series have been reported from other specialties, but these are often dismissed because they are not anaesthesia related. Rather than rejecting the observational results of performance by retrieval, emergency medicine, and military personnel, lessons should be learned from these valuable human data on emergency airway management. Understanding the impact of stress on performance might help to explain the poor results reported when anaesthetists operate jet ventilators during a CICO crisis. The outcome of the Fourth National Audit Project of the Royal College of Anaesthetists and Difficult Airway Society (NAP4) highlighted the impact of stress on anaesthetists during CICO crises while practising cannula cricothyroidotomy. An overall success rate of 37% by anaesthetists was in sharp contrast to 100% success by surgeons who used scalpels.[2] Many theories have been proposed to explain this disparity, but it is likely that the confidence and lower stress level associated with being a second responder was a factor in their success.

A large series of surgical cricothyroidotomies performed by army medics and army doctors in the field shows overall success rates of 67% for the medics and 85% for the army doctors; this, despite the fact that they are operating in conditions of extreme stress and personal danger.[18] Standard operating procedures are applied with a simple scalpel technique. This reduces the need for fine motor control. Training is designed to inspire confidence and emphasize simplicity. Equipment is standardized, and complex algorithms with multiple choices and alternative devices are eliminated. The benefit of reducing choice is consistent with several studies that have shown a significant increase in reaction time when subjects are confronted with multiple alternatives.[17] These principles have been adopted by recent airway management anaesthetic guidelines, which have moved away from the traditional menu philosophy. Instead of suggesting a range of options for CICO management, these guidelines have opted for a scalpel technique. This recommendation is based on clinical evidence, simplicity, and the ability to open the neck if necessary.

The largest single reported series of scalpel–bougie technique came from the London Air Ambulance Service. In 2014, Lockey and colleagues[19] reported 98 scalpel–bougie cricothyroidotomies with 100% success. These procedures were performed by anaesthetists and emergency medicine doctors on patients with a range of pathology and morphology. This success rate was attributed to the following factors: development of a positive mental attitude; immediate availability of equipment; the presence of a trained paramedic assistant; and a simple, well-practised technique.[20]

Several initiatives have been proposed to advance patient care during a CICO crisis. NAP4 recommended that each UK anaesthetic department should have a nominated airway lead (AWL),[21] and this was endorsed by the Royal College of Anaesthetists and Difficult Airway Society.[22] The main roles of the AWL include: (i) overseeing local airway training for anaesthetists and assisting in airway training more widely; and (ii) ensuring that local policies exist and are disseminated for predictable airway emergency procedures included in the Difficult Airway Society guidelines.[6] A recent editorial in the *BJA* (in press) entitled, 'Surgical intervention during a CICO event: emergency FONA?' by Pracy and colleagues stresses that departments should plan multidisciplinary team rehearsals, and the AWL should be responsible for the coordination of such multidisciplinary rehearsals.

The Royal College of Anaesthetists have now appointed AWLs in ~ 94% of all hospitals in the UK. It is further envisaged that their role will be to get involved in the collection of quality data through a reporting system along the lines of NAP4. Good outcome data are necessary if we are to progress on this issue. In addition, the Royal College of Anaesthetists are working on a FONA database. The latter is essential if we are to re-audit the impact of an initiative by the Difficult Airway Society to introduce a didactic approach to the management of the rare event that is CICO. The results should help to inform the ongoing re-evaluation of the guidelines using the best evidence available.

Existing human evidence supports the use of a scalpel FONA technique. Published case reports suggest that anaesthetists are able and willing to pick up a scalpel and successfully perform a scalpel–bougie technique.[19] Fears of extensive bleeding and trauma are unfounded, and reports of significant morbidity associated with a scalpel–bougie technique are acceptably rare.[19 23]

The emergency nature and infrequency of CICO and invasive rescue techniques make it unlikely that high-quality human studies will ever be available to support our choice of techniques. However, what is clear from observational studies is that cannula techniques cannot be relied upon to save lives and prevent severe morbidity. With appropriate training, scalpel techniques are reliable and easy to perform and have the potential to reduce mortality and morbidity in time-critical airway emergencies.

Declaration of interest

None declared.

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Special Issue

Systematic review of the anaesthetic management of non-iatrogenic acute adult airway trauma

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Abstract

Introduction: Non-iatrogenic trauma to the airway is rare and presents a significant challenge to the anaesthetist. Although guidelines for the management of the unanticipated difficult airway have been published, these do not make provision for the ‘anticipated’ difficult airway. This systematic review aims to inform best practice and suggest management options for different injury patterns.

Methods: A literature search was conducted using Embase, Medline, and Google Scholar for papers after the year 2000 reporting on the acute airway management of adult patients who suffered airway trauma. Our protocol and search strategy are registered with and published by PROSPERO (http://www.crd.york.ac.uk/PROSPERO, ID: CRD42016032763).

Results: A systematic literature search yielded 578 articles, of which a total of 148 full-text papers were reviewed. We present our results categorized by mechanism of injury: blunt, penetrating, blast, and burns.

Conclusions: The hallmark of airway management with trauma to the airway is the maintenance of spontaneous ventilation, intubation under direct vision to avoid the creation of a false passage, and the avoidance of both intermittent positive pressure ventilation and cricoid pressure (the latter for laryngotracheal trauma only) during a rapid sequence induction. Management depends on available resources and time to perform airway assessment, investigations, and intervention (patients will be classified into one of three categories: no time, some time, or adequate time). Human factors, particularly the development of a shared mental model amongst the trauma team, are vital to mitigate risk and improve patient safety.

Key words: airway management; blast injuries; blunt injuries; burns; wounds, penetrating

Trauma to the airway may cause acutely life-threatening airway laceration, obstruction, haemorrhage, and aspiration of blood; this presents the anaesthetist with a major challenge.[1 2] Fortunately, airway trauma is a relatively infrequent complication of major trauma, in both the UK civilian (National Health Service) and UK Defence Medical Services settings.[3 4] However, complications related to this injury can be catastrophic without optimal management. For example, in a patient with blunt or penetrating airway trauma, advancing a bougie or tracheal tube blindly beyond the vocal cords risks penetration through an airway laceration, leading to airway obstruction, pneumomediastinum, and the creation of a false passage.[1 5] Guidelines for the management of the unanticipated difficult airway have recently been revised by the Difficult Airway Society;[6] however, these do not make provision for an ‘anticipated’ difficult airway that could be experienced in complex trauma, and if followed, could even worsen

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the traumatic airway. Our aim was to inform best practice for airway trauma and suggest management options for the various injury patterns to reduce serious sequelae.

Methods

Search strategy

We searched Embase, Medline, and Google Scholar for papers reporting on the acute airway management of adult patients who had suffered airway trauma. We limited the search to articles published from the year 2000 onwards to represent contemporary practice. The search included full-text reports of articles from peer-reviewed journals and conference abstracts published in English, and there were no restrictions to the studies reviewed. In addition, the reference lists of the articles reviewed were scrutinized for additional relevant articles and book chapters.

Article selection

Titles and abstracts of the references obtained were reviewed by two independent reviewers (M.B. and C.P.J.). Articles were categorized for inclusion or exclusion. Articles were removed if both reviewers agreed independently to exclude. In the event of agreement to include or a discordant opinion, articles were reviewed in full by one of four independent reviewers (C.P.J., P.G., E.C., and S.J.M.). Inclusion criteria were as follows: adults older than 18 yr of age with airway trauma; papers published on or after 2000; and papers reporting airway trauma (blunt, burn, penetrating, blast, or miscellaneous injuries) and anaesthetic management. The exclusion criteria were as follows: children (<18 yr old); animal studies; papers not dealing with acute trauma and airway trauma; and papers that did not have an airway management focus. Our full protocol and search strategy are registered with and published by PROSPERO (http://www.crd.york.ac.uk/PROSPERO, ID: CRD42016032763); this includes the search terms and keywords used.

Results

Our systematic literature search yielded 578 articles (see Fig. 1). Two hundred and sixteen were excluded after title review. After abstract review, a further 214 articles were excluded. A total of 148 full-text papers were reviewed, of which we included 35 in this review. Figure 1 details reasons for inclusion and exclusion. We present our results categorized by mechanism of injury, as follows: blunt, penetrating, blast, and burns.

Blunt injury

Blunt airway trauma usually involves high-energy transfer; examples include assault, crush, fall from height, road traffic collision, pedestrian *vs* vehicle, hanging, accidental strangulation, and the 'clothesline' mechanism. Table 1 describes the various mechanisms of injury in blunt trauma and their associated injuries.

Patients who suffer blunt injury develop complex airway injuries, often as part of severe multisystem trauma. Failure to intubate, secure, and protect the airway in these patients are common factors that lead to an increase in morbidity and mortality.[7–9] Blunt airway trauma includes maxillofacial trauma, laryngotracheal trauma (LTT), and disruption of the trachea and bronchi. The sternum, cervical spine, and mandible shield the airway during trauma such that the incidence of blunt airway injury is low (~0.4%).[7–9] Despite being a rare pathology, the impact can be significant, with mortality rates of traumatic lesions below the vocal cords quoted as high as 63%.[10] Bronchial disruption occurs in 1% of chest trauma; most of these patients die at the scene.[11]

Maxillofacial trauma is the most common type of blunt airway trauma but does not usually present a problem because trismus is usually attributable to pain and therefore resolves on induction. The main issues to consider are then airway haemorrhage, hypoxia, and the risk of aspiration. Very rarely, trismus is the result of impaction of a condylar head fracture, causing a physical obstruction to mouth opening, which becomes apparent only after rapid sequence induction.[12]

The cricoid cartilage and cricothyroid membrane are involved in 50% of instances of blunt airway trauma with airway compromise; injury to the thyrohyoid membrane, thyroid cartilage, and extrathoracic trachea account for the remainder.[1 13] Laryngotracheal separation occurs in up to 63% of instances, usually between the cricoid and fourth tracheal cartilage.[14 15] The airway can remain patent if spontaneous respiration is maintained by splinting of peritracheal connective tissue.[16] This situation is precarious and can deteriorate rapidly.[17]

Blunt trauma at the level of the larynx or below can be difficult to diagnose and life threatening if managed poorly. Patients can present with non-specific signs and symptoms, such as cough, dyspnoea, aphonia, stridor, laryngeal crepitus, haemoptysis, and subcutaneous emphysema. These symptoms do not correlate well with the anatomical site of the lesion;[14 15] however, complaints of haemoptysis and stridor at presentation have been associated with severity of injury.[16 18]

In view of the poor relation between signs and severity of injury, the clinician must have both a high index of suspicion and a low threshold for further investigations, including plain X-rays (chest and lateral cervical spine) to rule out surgical emphysema, pneumothorax, or both. Nasendoscopy is useful and permits assessment of vocal cord movement, integrity of the laryngeal mucosa, and airway patency.[13] Computed tomography is the gold standard and detects the site of injury in 94% of blunt trauma.[19] Bronchoscopy is considered the best diagnostic tool for suspected lesions below the vocal cords,[11 14 20] but utility in acute airway compromise is limited because it is a skilled technique and access to equipment may be limited. The severity of blunt airway trauma has been classified by Schaefer and Close[21] (Table 2).

Trauma to the upper and lower respiratory tract should be managed on a patient-by-patient basis. Minor instances of blunt airway trauma should be observed in the critical care unit, with reassessment of the airway at regular intervals for at least 48 h. The management of major blunt airway trauma is governed by the degree of patient cooperation and a risk–benefit analysis. The safest approach to patients requiring intubation is to instrument the trachea under direct vision to avoid entering a tear, creating a false passage, or disrupting the airway completely.[1] It is preferable to do this with the patient awake and breathing spontaneously.

Following these principles, there are three judicious approaches to airway management . First, performing an awake tracheostomy under local anaesthesia is a common intervention of choice for LTT.[18] However, this technique requires a high degree of operator skill, may be difficult, and is limited by patient cooperation and teh time taken to assemble skilled assistance.[16 22 23] It is important to note that surgical cricothyroidotomy and percutaneous cricothyroidotomy are contraindicated in these patients because they may lead to further airway disruption.[11 18 24] This is not the case for tracheobronchial trauma because the lesion is commonly more distal, with 76% of injuries occurring within 2 cm of the carina, and 43% occurring within the first 2 cm of the right main bronchus.[25 26]

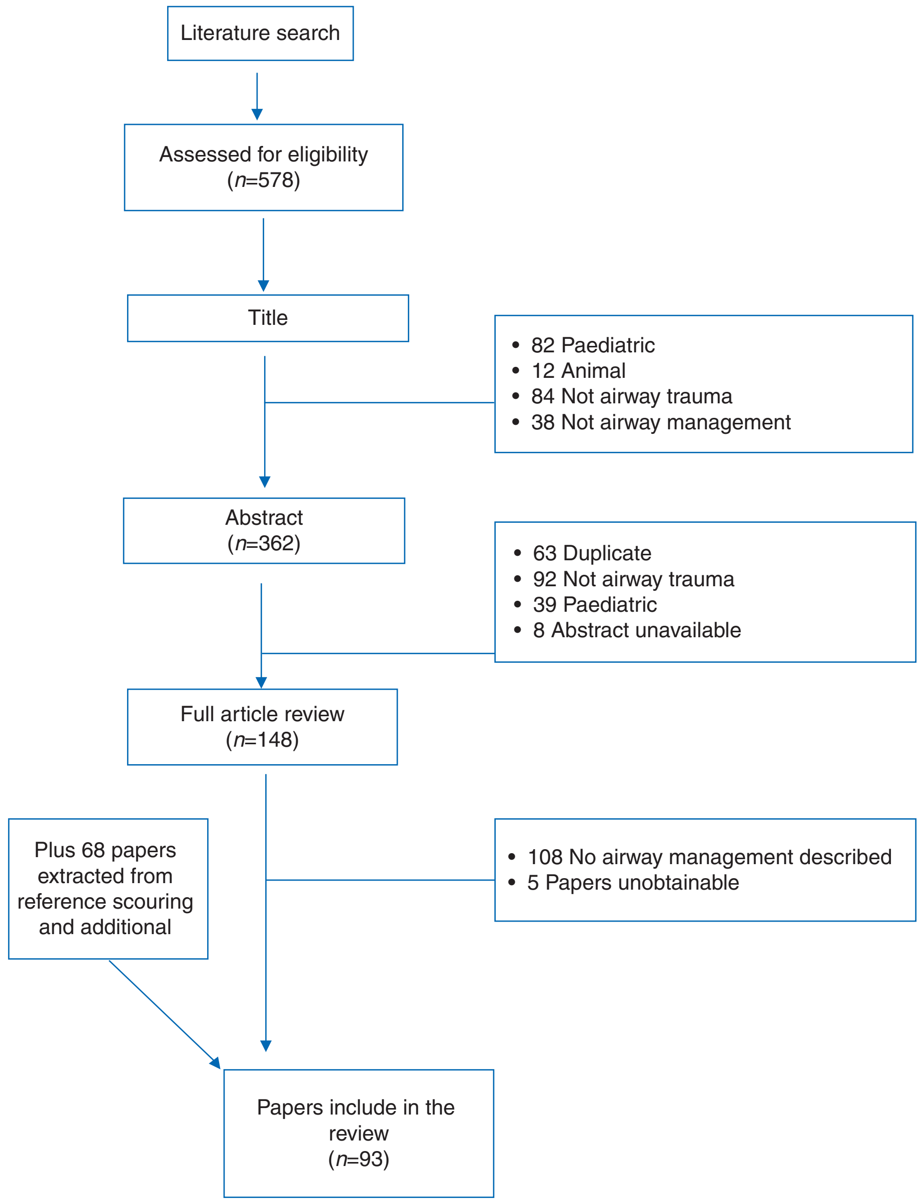


Fig 1 Systemic review literature search flow chart.

Second, awake fibreoptic intubation is an alternative technique, which maintains spontaneous ventilation and allows simultaneous airway assessment and placement of a tracheal tube distal to any pericarinal defect.[22 23] Care must be taken when railroading the tracheal tube so that its bevel does not catch on a tear, extending the injury.[27] This can be avoided by using a lubricated small-diameter tube, fitting snuggly onto the scope, and twisting the tube so that its bevel faces any lesion during its advancement into the trachea. The use of the Lightwand in blunt trauma has also been described.[28]

Third, conventional intubation is a rapid way of securing the airway but risks intubating a tear, creating a false passage, or disruption of the larynx or trachea.[21 29] Consequently, we recommend fibrescope-assisted direct or videolaryngoscopy as part of a modified rapid sequence induction (with no cricoid pressure or positive pressure ventilation because both may aggravate the injury).[30 31] A small-diameter tracheal tube should be placed at the introitus of the larynx under direct vision, and then a fibrescope is passed through the tube and into the trachea. The tracheal tube can then be delivered past the lesion safely if the bevel is orientated to face the lesion. Modified rapid sequence induction and rigid bronchoscopy is an alternative choice, because airway inspection is simultaneous with intubation. This technique requires a high degree of operator skill and needs appropriately trained personnel but can deal effectively with distal tracheal or bronchial disruption.[11 18 32] A summary of the associated problems and cautions in relation to the anatomical territory is presented in Table 3. The technique of choice depends upon the patient's condition, urgency, and the experience of the anaesthetist and surgeon.[33]

Table 1 The mechanisms of injury associated with blunt trauma to the airway[7]

Type of trauma	Mechanisim of injury	Airway injury
Road traffic collision	Severe flexion/extension	Tracheal tears
Fall	Rapid deceleration	Fractures of the larynx
		Laryngotracheal separation
Hanging	Direct blows	Fractured thyroid or cricoid cartilages, or both
Accidental strangulation		Layrngotrachael separation
'Clothesline' mechanism		
Assault		
Crush	Crush injuries to chest	Tracheobronchial disruption
Pedestrian *vs* vehicle	Sudden, explosive increase in intrathoracic pressure against a relatively closed glottis	
	Rapid deceleration shears airways at fixed points: cricoid cartilage and carina	Transection at carina or cricotracheal junction
	Pulmonary compression tears the airway at the level of the carina	Carinal tear

Table 2 Classification of the severity of blunt airway injury (adapted from Schaefer and Close)[21]

Group 1	Minor endolaryngeal haemotoma, laceration, or both No detectable laryngeal fracture
Group 2	Laryngeal oedema, haemotoma, or both Minor mucosal disruption, but no exposed cartilage
Group 3	Massive oedema, large mucosal lacerations, exposed cartilage, displaced fracture, vocal cord immobility
Group 4	As group 3 plus comminuted or unstable fracture

Penetrating and blast injury

Penetrating injuries to the face and neck are uncommon in both civilian[25 34] and military[3 35] populations. However, the incidence is increasing in military personnel because modern body armour does not protect the face and neck.[26 34 36–38] Airway wounds can cause immediate life-threatening compromise[34] because of the density of vital structures within the neck.[1 2 39 40] Indeed, on exploration, a clinically superficial stab wound may reveal a vascular or aerodigestive injury.[3 4 32] Blast-induced injuries result from direct or indirect exposure to an explosion and have high potential for an associated upper airway injury,[5 34 41] the most severe of which is complete disruption of the airway.[1 35 42]

The causes of penetrating airway trauma are diverse and include assault or self-inflicted injuries with firearms or knives.[36–38 40] Facial wounds are usually the result of gunshot[2 7 9 38 39 43–45] or blast injuries.[4 10 46–53] Objects or projectiles can transfix the mouth and limit mouth opening.[11–15 25 34 40–45 54 55] Patients may also present with neck lacerations and open wounds to the airway.[2 16 38 40] Gunshot and blast injuries result in penetrating neck trauma,[25 46–53] so the clinician must always consider the likely trajectory of projectiles or fragments and their potential airway effects. The location of great vessels in the neck adjacent to the airway means that haemorrhage can impact airway patency,[14 15 54 56] with high mortality.[16 18 34 43 44 45 54]

When assessing these patients, an effective approach is to divide the structures of the head and neck into three zones.[13 39 55] Zone 1 is from the clavicles to the cricoid cartilage, zone 2 from the cricoid cartilage to the angle of the mandible, and zone 3 from the angle of the mandible to the base of the skull. Zone analysis predicts potential injuries and the need for urgent airway management solutions.[5 19 25] Blood loss and upper airway obstruction are the major determinants of injury severity.[14 38 40]

Wounds in the anterior and lateral aspects of the neck compromise the airway more often than those in the posterior region.[11 20 25 40 42] The clinician should also consider the presence of blood and debris within the lumen of the airway, injury within the airway wall itself, or injury outside the wall (e.g. expanding haematoma or surgical emphysema). If possible, computed tomography is the first-line investigation in stable patients with penetrating neck injuries[21 35 56] in order to identify the location of an airway injury.

As with blunt injuries, major penetrating and blast airway trauma management is governed by the degree of patient cooperation and a risk–benefit analysis. Potential difficulties to consider are neck haematoma or subcutaneous emphysema around the airway that can distort anatomy and impair tracheostomy. Fibreoptic intubation is difficult if blood or debris is present within the airway. Regardless, awake fibreoptic intubation in skilled hands has proved effective.[1 18 39 41 43–45 54 57]

The literature suggests that the safest approach to patients requiring intubation is to instrument the trachea under direct vision in order to avoid entering a tear, creating a false passage, or disrupting the airway completely.[5 16 22 23 50 58] It is preferable to do this with the patient awake and breathing spontaneously. Similar to blunt trauma, awake tracheostomy is the intervention of choice,[5 11 18 22 23 25 26 35 38 40 42 59–64] and surgical or percutaneous cricothyroidotomy are contraindicated.[27 59] It is important to consider thoracotomy if a patient presents with chest trauma, and low tracheal or bronchial transection standard tracheostomy in this situation will result in malposition distal to the defect. Awake fibreoptic intubation is an alternative option to permit simultaneous airway assessment and placement of a tracheal tube distal to any laceration.[21 29 41 45 57 65 66] As emphasized already, great care must be taken when railroading the tracheal tube so that its bevel does not extend a laceration. A modified

Table 3 A summary of the the associated problems and cautions in relation to the anatomical territory in blunt injury. LTT, laryngotracheal trauma

Anatomical territory	Associated problems	Caution: red flag signs and symptoms
Maxillofacial	Traumatic brain injury and base of skull fracture Cervical spine fracture Ophthalmic injury Vascular injury Aspiration of blood and debris	Signs of elevated intracranial presssure Neurological deficit Neurogenic shock Significant bleeding from fracture displacement Bilateral anterior mandible fractures and airway obstruction Ventilatory failure
Laryngotracheal	Cervical fracture Vascular injury Oesophageal injury Rib fractures and flail segment Pneumothorax Haemothorax Pneumomediastinum Pulmonary contusion	Haemoptysis and stridor have previously been reported as cardinal features of severe LTT Massive surgical emphysema Ventilatory failure Cardiovascular collapse
Trachea and bronchi	Vascular injury Oesophageal injury Rib fractures and flail segment Pneumothorax Haemothorax Pneumomediastinum Pulmonary contusion	Haemoptysis Massive surgical emphysema Ventilatory failure Cardiovascular collapse

rapid sequence induction and fibreoptic-assisted direct or videolaryngoscopy may be undertaken if a general anaesthetic must be administered immediately. However, the clinician should avoid neuromuscular blocking agents (muscle tone may be important for airway integrity in airway transection)[30,50,58,67] and be cognizant that conventional intubation risks intubating a tear.[5,31,68] We suggest that this may be mediated by fibrescope-assisted direct or videolaryngoscopy as part of a modified rapid sequence induction (with no cricoid pressure or positive pressure ventilation). A tracheal tube should be placed above the vocal cords under direct vision and then a fibrescope passed through the tube and into the trachea. The tracheal tube can then be delivered safely as described above. Large neck wounds can be intubated directly over a fibrescope in this manner. Combined usage of an Airway Scope and gum elastic bougie for emergency airway management in a patient with a neck stab wound has also been described,[69] as has the use of the AirTraq in traumatic asphyxiation,[70] and the use of the Lightwand.[28] A summary of the associated problems and cautions in relation to the anatomical territory for non-iatrogenic injury to the airway caused by penetrating injury is presented in Table 4.

Burns

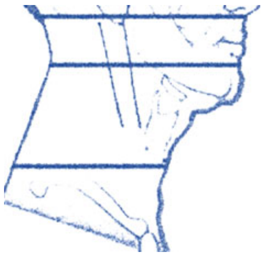
Burns to the upper airway caused by direct heat and steam injury, electrocution, or contact with corrosive chemicals can lead to marked swelling of the face, tongue, epiglottis, and glottis and result in airway obstruction.[11,18,25,32,34,60–64,71] Airway swelling may not occur immediately but may develop over a period of hours (exacerbated by fluid resuscitation). Therefore, a high index of suspicion and frequent re-evaluation of the airway are essential.[3,35,65,72–74] Thermal injury is primarily restricted to structures above the vocal cords, unless steam is inhaled, because the oropharynx and nasopharynx act as an efficient heat sink.[26,34,36–38,66,74] Smoke inhalation delivers a pathological insult to the lungs as a result of the particulates, respiratory irritants, and systemic toxins that it contains.[34,75] In this context, it is necessary to look for and treat carbon monoxide[76] and cyanide poisoning.[77]

Inhalation injury is a greater contributor to overall morbidity and mortality than either body surface area percentage or age[57,67] and is present in 60% of central facial burns.[61,68] Burns patients without smoke inhalation have a mortality of 2%, compared with a mortality of 30% with this type of injury.[78]

Patients who present acutely with facial and neck burns have two predominant airway issues: airway obstruction and smoke inhalation. These risks prompt the early intubation of high-risk patients,[75,79,80] because the rate of difficult intubation increases from 11.2 to 16.9% if delayed (owing to the development of airway oedema).[61,62,71,81] However, intubation is not without risk, and the clinician should carefully evaluate individual patients.[72–74,82] Nasendoscopy is an important tool to diagnose the extent and severity of an airway burn, and serial nasendoscopy of vocal fold oedema has been used to predict the need for intubation in patients at risk.[66,74] Fibreoptic bronchoscopy supports the diagnosis of smoke inhalation and may reveal carbonaceous debris, erythema, or ulceration.

Intubation is mandated in instances of heat and smoke inhalation injury combined with facial, neck, or extensive body burns. In contrast, physiologically stable patients with smoke inhalation injury but no facial or neck burns may be monitored by nasal endoscopy and intubated later.[57] In addition to airway oedema, other causes of difficulty include limited mouth opening and intractable trismus in electrical burns.[61] Mask ventilation may also be challenging because of the presence of dressings and exudates,[42,78] and the application of nasal oxygen should be

Table 4 A summary of the the associated problems and cautions in relation to the anatomical territory for non-iatrogenic injury to the airway caused by penetrating injury



Anatomical territory	Associated problems	Caution: red flag signs and symptoms
Zone 3	Cranial nerve injury Oesophageal injury Vascular injury (to branches of the external carotid artery, internal carotid artery, vertebral artery, and internal jugular and facial veins)	Neurological deficit Neurogenic shock Odynophagia Haematemesis Air bubbling from wound
Zone 2	Oesophageal injury Vascular injury (to common carotid, carotid bifurcation, vertebral arteries, and jugular veins)	Massive surgical emphysema Expanding or pulsatile haematoma Active bleeding Cardiovascular collapse
Zone 1	Oesophageal injury Vascular injury (to subclavian and innominate vessels, common carotid and lower vertebral arteries, and jugular veins)	Haemoptysis

considered. This can significantly boost the effective inspired oxygen and can be left on during tracheal intubation attempts. The application of additional nasal oxygen during intubation has been termed NO DESAT).[83]

For an anticipated difficult airway, clinical examination and nasendoscopy will provide vital information; however, this does depend on the degree of patient cooperation and the severity of the injury. Minor injuries can be managed conservatively in a monitored (high-dependency unit) setting. For major burns requiring immediate treatment, for cooperative patients awake fibreoptic intubation should be considered if the preoperative evaluation reveals concern for upper airway patency or difficult mask ventilation.[79] For severe injuries or non-compliant patients, a primary surgical airway is mandated.[61 62 81] Tracheostomy may also be indicated if a laryngeal injury is suspected.[82 84] In uncooperative patients or those with less severe pathology on clinical examination and nasendoscopy, rapid sequence induction followed by videolaryngoscopy is appropriate. One article described the use of the Combitube in the airway management of burns patients.[85]

After intubation, the tube should be secured carefully because accidental extubation may have fatal consequences.[86] Fixation methods include wiring the tube to a tooth and the use of archbars. The tracheal tube should be left uncut because facial swelling can cause it to retreat into the oropharynx, requiring re-intubation at the worst possible time. A summary of the associated problems and cautions in relation to the anatomical territory for non-iatrogenic injury to the airway caused by burn injuries is presented in Table 5.

Conclusion

Our systematic review of the literature on acute adult non-iatrogenic airway trauma has highlighted common themes that should guide the clinician. The hallmark of airway management in these patients is the maintenance of spontaneous ventilation if at all possible, intubation under direct vision to avoid the creation of a false passage, and the avoidance of both intermittent positive pressure ventilation and cricoid pressure during a rapid sequence induction. This situation is distinct from the management of an unanticipated difficult airway. Here, adherence to the Difficult Airway Society 2015 guidelines[6] could even worsen the situation in this patient population because cricoid pressure, positive pressure ventilation either via a face mask or a supraglottic airway device, and surgical cricothyroidotomy are all contraindicated.

Consequently, if the primary intubation plan fails, there is only one rescue plan to avoid making the situation worse, namely surgical tracheostomy. The management of burns patients is broadly similar but with the caveat that the Difficult Airway Society 2015 guidelines[6] apply throughout because the clinician is not faced with the problem of an airway laceration or transection.

Ultimately, when considering all these types of airway traumas, the clinician is faced with a time-management issue, with a patient being classified into one of three groups: no time, some time, or adequate time for airway assessment, investigation, and intervention. If the patient is in extremis and there is no time for assessment, the anaesthetist must manage the patient urgently while planning for the worst-case scenario; a false passage in blunt, penetrating, and blast trauma, for example. If the airway appears stable then there is adequate time for assessment, planning, and intervention in optimal conditions. Most patients are somewhere between these two extremes, such that informed decision making is crucial for the anaesthetist because the situation can be worsened or stabilized by their subsequent actions. For example, allowing a patient to assume their most comfortable position, be that sitting, lateral, or prone, may 'buy enough time' to undertake nasal endoscopy or computed tomography.[4] Objects that impale the patient should be trimmed carefully so they do not impede subsequent airway interventions.[42 87] Finally, location is very important; it could be safer to transfer the patient to theatre to secure the airway, especially if a tracheostomy is required, because there is more space, better lighting, and staff more familiar with the intervention.

Human factors are key to the management of a complex anticipated airway problem.[88 89] The recently revised Difficult Airway Society Guidelines for the management of an unanticipated difficult airway[6] devote a significant section to these. Leadership, followership, teamwork, and situational awareness and communication amongst the team are all vital to ensure that the airway is safely secured. A trauma team will often have 10–15 min to prepare to receive a patient once they have been activated.[84] During this period, the anaesthetist should consider the likelihood of airway trauma and the possible investigations

Table 5 A summary of the the associated problems and cautions in relation to the anatomical territory for non-iatrogenic injury to the airway caused by burn injuries

	Anatomical territory	Associated problems	Caution: red flag signs and symptoms
	Face, tongue, and oropharynx	Pulmonary oedema Cardiovascular dysfunction Carbon monoxide and cyanide poisoning	Evidence of thermal or chemical injury to face, lips, mouth, pharynx, or nasal mucosa Inflammation, blistering, oedema, and mucosal lesions Hair singeing Soot in mouth
	Larynx		Stridor Hoarseness
Ensure primary survey completed to assess for other traumatic injuries Avoid task fixation with burns	Trachea, bronchi, and distal airways		Carbonaceous sputum Dyspnoea Hypoxaemia Increased concentrations of carbon monoxide and cyanide may not cause cyanosis Decreased level of consciousness, confusion, or signs of cerebellar dysfunction Mortality increases significantly with inhalation injury

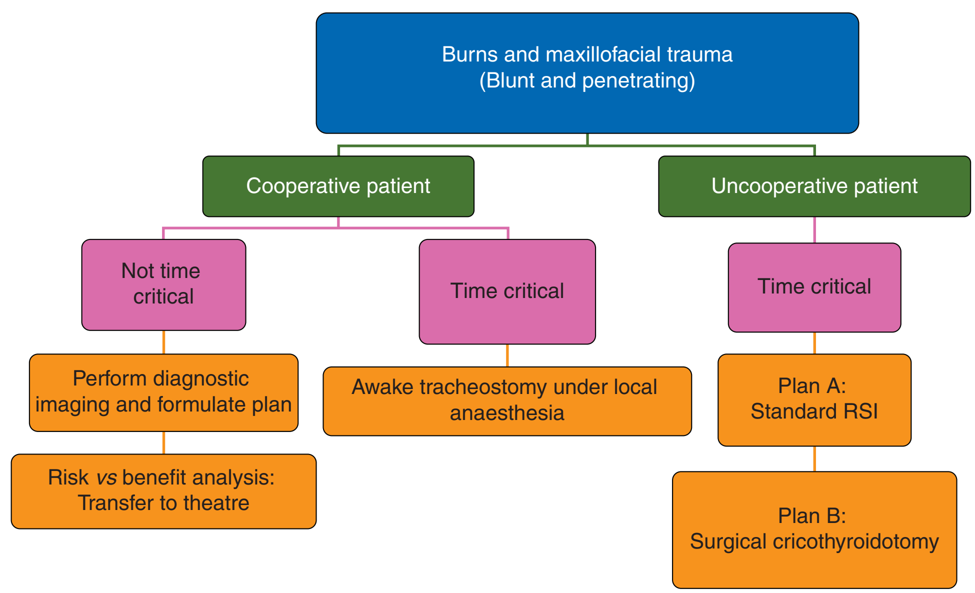


Fig 2 An example of shared mental model maps for burns and maxilliofacial trauma. RSI, rapid sequence induction.

and airway interventions required. This includes consideration of what personnel and equipment are needed and specifically who will perform a tracheostomy or surgical cricothyroidotomy if required. The UK Defence Medical Services have developed the concept of a 'command huddle',[90] where decisions are made by a senior team about further management after the primary survey. A conversation around airway management (if it has not already taken place) should occur here, with a discussion around the airway technique of choice.

The majority of anaesthetists have limited exposure to complex airway trauma and need to develop shared mental models to optimize management techniques; examples of these are included in Figs 2 and 3. Our review presents contemporary evidence in management of airway trauma to inform clinical practice. The clinician should also consolidate knowledge through mechanisms such as high-fidelity simulation scenarios[91] and by attending workshops specifically for the management of airway trauma.

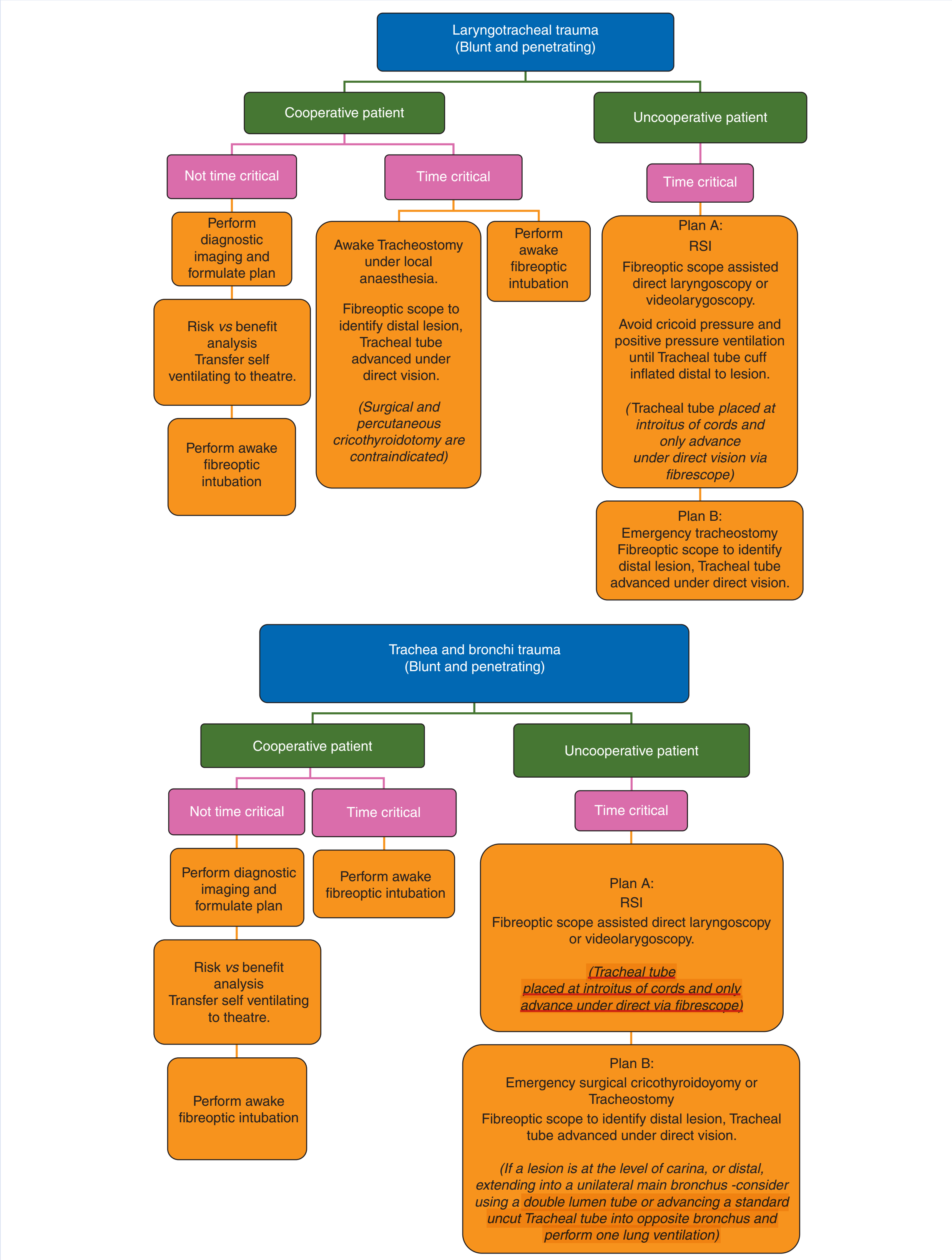


Fig 3 A shared mental model map for laryngotracheal trauma (blunt and penetrating). RSI, rapid sequence induction.

Authors' contributions

Substantial contributions to the conception or design of the work: B.M., S.J.M., P.G.
Acquisition of data: S.J.M., P.G., M.B., C.P.J., E.C.
Analysis of data: B.M., S.J.M., P.G., M.B., C.P.J., E.C.
Interpretation of data: B.M., S.J.M., P.G., M.B., C.P.J., E.C.
Drafting work for important intellectual content: B.M., S.J.M., P.G., C.P.J.

Declaration of interest

B.M. has received an honorarium for a lecture by Grifols, Inc.; this represents no conflict of interest for the submitted manuscript. S.J.M., C.P.J., M.B., E.C. and P.G. have no conflict of interest to declare.

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Ultrasonographic identification of the cricothyroid membrane: best evidence, techniques, and clinical impact

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Abstract

Inability to identify the cricothyroid membrane by inspection and palpation contributes substantially to the high failure rate of cricothyrotomy. This narrative review summarizes the current evidence for application of airway ultrasonography for identification of the cricothyroid membrane compared with the clinical techniques. We identified the best-documented techniques for bedside use, their success rates, and the necessary training for airway-ultrasound-naïve clinicians. After a short but structured training, the cricothyroid membrane can be identified using ultrasound in difficult patients by previously airway-ultrasound naïve anaesthetists with double the success rate of palpation. Based on the literature, we recommend identifying the cricothyroid membrane before induction of anaesthesia in all patients. Although inspection and palpation may suffice in most patients, the remaining patients will need ultrasonographic identification; a service that we should aim at making available in all locations where anaesthesia is undertaken and where patients with difficult airways could be encountered.

Key words: airway, anatomy; airway, complications; airway, obstruction; airway, patency; cricothyrotomy; tracheostomy; ultrasonography

Access via the anterior neck, preferably via the cricothyroid membrane, is recommended as a last resort by all major guidelines for difficult airway management in the event of oxygenation failure where the airway cannot be managed successfully with tracheal intubation, face mask ventilation, or supraglottic airway insertion.[1–6] Additionally, the cricothyroid membrane may serve as a route for application of local anaesthetics before awake intubation, retrograde awake intubation, awake placement of a cannula cricothyrotomy, and awake surgical cricothyrotomy. The success rate of real emergency airway access performed by anaesthetists is low, with only 9 of 25 (36%) attempts being successful.[7] An inability to identify the cricothyroid membrane is an important contributor to this high failure rate,[8] because misplacement is the most common complication when attempting cricothyrotomy.[9] Despite its key role in airway management, the success rate for anaesthetists in identifying the cricothyroid membrane with traditional modalities of inspection and palpation is notoriously low, especially in obese patients, for whom reported success rates vary between 0 and 39%.[10–13]

The aim of this narrative review is four-fold: first, to summarize the current evidence for identification of the cricothyroid membrane using ultrasound and the clinical application of these techniques; second, to compare success rates of the individual clinical methods of identification of the cricothyroid membrane with the rates obtainable by ultrasonography; third, to identify the most well-proved techniques and to provide detailed

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descriptions of these techniques in sufficient detail with complimentary video links to allow clinicians to practice for clinical use; and fourth, to provide clinical recommendations based on the above findings.

The PubMed database was searched for relevant articles using the search strategy '[(ultrasound OR ultrasonography OR sonography) AND (trachea OR cricothyroid membrane OR tracheostomy OR cricothyrotomy)]', and major textbooks of airway management and of ultrasonography were also searched. Subsequently, we scrutinized reference lists of the included studies and retrieved the papers that were cited. The publications in languages other than English (German, Japanese, and French) were translated into English. We scrutinized these resulting papers, and subsequently, we used the Web of Science™ to see whether these papers had themselves been cited, subsequently retrieving the papers in which they were cited.

We included publications that described the ultrasonographic appearance of the cricothyroid membrane, the technique for identification of the cricothyroid membrane, and publications that described clinical use of ultrasound-guided identification of the cricothyroid membrane in comparison to traditional modalities. We excluded publications describing the use of ultrasonography for tracheostomy (whether it was surgical or a percutaneous dilatational technique) in instances where a tracheal tube was already in place.

Results of the literature search are summarized in Table 1.

Identification of the cricothyroid membrane with clinical techniques only

Three different clinical techniques (palpation, visual inspection, and the 'four finger widths technique') for identifying the cricothyroid membrane were documented (Table 1).

Success rates of identification by palpation varied with sex, patient positioning, and body habitus. In males, it was reported to be successful in 72% of non-obese[12] and in 39% of obese subjects.[12] In females, success rates were 24,[12] 25 (neutral position),[10] 29 (hyperextended neck),[10] and 71% in the non-obese,[13] whereas they were found to be 0 (neutral position),[10] 6 (hyperextended neck),[10] 35,[12] 37,[11] and 39%[32] in obese females. In heterogeneous populations including a mixed population of both sexes and with various BMI, a wide range of success rates was found, as follows: 19,[29] 30,[16] 39 (cadaver),[32] 46,[21] 62,[33] 66.7,[34] and 70%.[29]

Identification of the cricothyroid membrane by visual inspection of the overlying skin creases was successful in 50%.[33] The 'four finger widths technique' was successful in 46% of patients in a mixed population.[33]

Identification of the cricothyroid membrane with ultrasonography

In a high fraction of studies (Table 1), the ultrasound examinations were performed by one or two clinicians only, and ultrasonography was often applied purely as a descriptive technique[17 31] or as a reference method[10 12 13 16 29 33] in studies that investigated success with clinical methods. In the latter studies, the success rate is invariably 100%.

Two additional studies described ultrasound examinations performed by only two clinicians: Curtis and colleagues[24] described 95% success rate in 21 cadavers in a mean of 3.6 s and Nicholls and colleagues[15] obtained 100% success in 50 clinical examinations in a mean of 24 s. All case reports described 100% success in finding the cricothyroid membrane using ultrasound.[14 23 30]

Studies comparing palpation and ultrasonography in manikins, cadavers, and humans

In a non-anatomical manikin, when 25 clinicians used palpation to identify the cricothyroid membrane, cannulation of the airway was successful in only 44%, compared with 83% when ultrasonography was used.[22]

A cadaveric[32] study randomizing 23 anaesthetists showed that palpation and trocar cricothyrotomy was successful in 39%, compared with 63% when using ultrasonography, albeit longer [mean (SD) 111 (47) *vs* 196 (61) s, respectively]. Ultrasonography training here comprised a 10 min lecture on cricothyrotomy, 3 min video, and five hands-on attempts on the cadaver.

Three clinical studies investigated the success of palpation *vs* ultrasonography in a larger heterogeneous group of clinicians.[11 21 34] Successful identification of the cricothyroid membrane with palpation alone was reportedly 67% in lean subjects,[34] 46% in a mixed BMI cohort,[21] and 37% in the morbidly obese.[11] With ultrasonography, this improved to 69% in lean subjects,[34] 100% in mixed BMI subjects,[21] and 83% in morbidly obese subjects.[11] Ultrasonography 'training' *per se* was varied, and ranged from a 'brief surgical airway anatomy and ultrasonography training'[34] and a 'theoretical airway ultrasonography and 15 min hands-on training'[21] to 'a structured teaching program consisting of e-learning, a 20-minute lecture on airway ultrasonography and 20 min of hands-on training'.[11] Six months after the original ultrasonography training, the clinicians still had higher success in finding the cricothyroid membrane using ultrasound than with clinical examination (78 *vs* 33%, $P<0.05$).[21]

Positioning and types of ultrasonographic techniques

Mallin and colleagues[27] reported a 100% success rate with ultrasonography when performed by 23 physicians acting as both models and investigators. The time to successful identification of the cricothyroid membrane was not reported. They found that ultrasound-guided marking of the cricothyroid membrane of healthy volunteers before simulated intubation accurately identified the cricothyroid membrane also after the simulated intubation, even after the head and neck were brought back into the initial extended-neck position. Their training consisted of watching a short video of unspecified duration.[27] When a cohort of 42 anaesthetists compared two ultrasonography techniques (transverse and longitudinal) to best identify the cricothyroid membrane in a randomized sequence on morbidly obese females, success rates of 90% were achieved with each technique in a mean of 24 (transverse technique) and 37 s (longitudinal technique), respectively.[37] One hundred per cent of the anaesthetists were able to identify the cricothyroid membrane with at least one of the techniques. The ultrasonography education consited of a 1 h structured training programme that included e-learning, a lecture, and hands-on training.[37]

Gleaning the results from the published literature, we can draw the following conclusions: (i) the identification of the cricothyroid membrane by clinical measures (inspection and palpation) alone is insufficient in a high fraction of patients, especially the obese; (ii) ultrasonography improves the accuracy of identification of the cricothyroid membrane, with a success rate very close to 100% once the clinicians have gained some experience; (iii) after a structured training programme lasting ~1 h, it is possible to attain a clinically useful skill level; (iv) the ultrasound-

Table 1 Publications describing the ultrasonic appearance of the cricothyroid membrane or the technique for ultrasound-guided identification of the cricothyroid membrane or presenting data on the ultrasound-guided or clinical (visual or palpation-guided) identification of the cricothyroid membrane. CTM, cricothyroid membrane; 3D, three-dimensional; MRI, magnetic resonance imaging; n.a., not assessed; US, ultrasonography

Publication	Study design	Subjects (human, cadaver, or manikin); *n*; characteristics	Physicians identifying the CTM (*n*)	Physicians who performed the US (*n*); US training for the study	Description of the US appearance of CTM	Identification of CTM by palpation (success rate; duration)	Identification of CTM with US (success rate; duration)	US technique for identification of the CTM	Technique described in detail for replication and applicable without palpable landmarks (yes/no)	Comments
Orr and colleagues[14]	Case report, CTM identified before awake intubation	Human; 1; difficult airway	1	1; n.a.	n.a.	0/1=0%; n.a.	1 of 1=100%; n.a.	n.a.	No	
Nicholls and colleagues[15]	Identification of the CTM with US	Humans; 50 patients; mean BMI 26 kg m^{-2}	2	2; cadavers	Bordered by the very echogenic thyroid and cricoid cartilages	n.a.	Success in all 50 patients; time to viewing 24.3 s	Longitudinal initially, then transversely on the CTM	No	Palpation before ultrasound
Elliott and colleagues[16]	Palpation study, with US as reference	Humans; 2 male and 4 female subjects; BMI 24–53 kg m^{-2}	18	2; n.a.	n.a.	30%; n.a.	100%	n.a.	No	
Singh and colleagues[17]	Descriptive	Humans; 24 volunteers; mean BMI 24 kg m^{-2}	1	1; n.a.	Hyperechoic band	n.a.	n.a.	n.a.	No	
Kristensen[18]	Descriptive	Humans	n.a.	n.a.; n.a.	Hyperechoic band	n.a.	n.a.	Stepwise. Trachea in transverse, transducer then rotated to sagittal plane.	Yes	
Kundra and colleagues[19]	Descriptive	Human; n.a.	n.a.	n.a.; n.a.	Hyperechoic band	n.a.	n.a.	Sagittal, parasagittal, and transverse	No	
De Oliveira and colleagues[20]	Case report. US-guided identification after failed palpation	Human; 1; BMI 57 kg m^{-2}	1	1; n.a.	n.a.	0 of 1=0%; n.a.	1 of 1=100%; n.a.	CTM between inverse V-shaped thyroid cartilage and arch-like cricoid, as in Barbe and colleagues[21]	Yes	

Continued

Table 1 *Continued*

Publication	Study design	Subjects (human, cadaver, or manikin); *n*; characteristics	Physicians identifying the CTM (*n*)	Physicians who performed the US (*n*); US training for the study	Description of the US appearance of CTM	Identification of CTM by palpation (success rate; duration)	Identification of CTM with US (success rate; duration)	US technique for identification of the CTM	Technique described in detail for replication and applicable without palpable landmarks (yes/no)	Comments
Dinsmore and colleagues[22]	Palpation *vs* US for cannulation	Manikin, non-anatomical	50	25; 6 min education	n.a.	Cannulation 44%; median 110 s	Cannulation success 83%	Transverse on the simulated trachea; CTM		
Aslani and colleagues[10]	Palpation study, with US as reference	Humans; 56 female subjects, 41 non-obese and 15 obese; BMI 40.5 kg m^{-2}	24	2	n.a.	Neutral: obese 0%, non-obese 25%; Extended: obese (6%), non-obese (29%)	100% success by the two ultrasound examiners; n.a.	Transducer transversely, moving, vocal cords appeared. The probe was moved to see the CTM as in Barbe and colleagues[21]	No	
Suzuki and colleagues[23]	Case report. US-guided localization before awake intubation	Human; 1; cervical spine disease	n.a.	1; n.a.	n.a.	n.a.	1 of 1=100%	Transverse approach	No	
Curtis and colleagues[24]	US-guided cricothyrotomy	Cadavers; 12 female and 9 male cadavers; mean BMI 21.9 kg m^{-2}	2	2	n.a.	n.a.	95%; 3.6 s (cricothyrotomy median 26.2 s)	Sagittal orientation placed just lateral to the midline of trachea	No	
Tsui and colleagues[25]	Comparing US in humans and cadavers	Humans and cadavers; n.a.	n.a.	n.a.; n.a.	n.a.	n.a.; n.a.	n.a.; n.a.	Gradual change of the CTM to the cricoid arch	No	
Or and colleagues[26]	Comparing 3D US and MRI	Humans; 11 volunteers; BMI<35 kg m^{-2}	n.a.	1	A hyperechoic band between the cartilages	n.a.; n.a.	n.a.; n.a.	n.a.	No	3D US images correlate well with MRI
Mallin and colleagues[27]	Identified CTM. Changed position of subjects. Subsequently, rescanned	Humans; 23; healthy volunteers	23	23	n.a.	n.a.; n.a.	23 of 23=100%; n.a.	Longitudinal lateral to midline, followed by 90° rotation and marking	No	Marking of the CTM consistent after attempted intubation

Barbe and colleagues[21]	Compared palpation with US	Humans; 2, female and male; BMI 35.4 and 29.8 kg m^{-2}	12	12 (+2 instructors); theoretical airway US training plus 15 min hands on	Hyperechoic line with a posterior artefact	46% (of 24 examinations); 15 and 24 s, respectively	100% (of 24 examinations); 21 and 28 s, respectively	Transversely, thyroid cartilage 'V', then CTM delimited caudally by arch-like cricoid cartilage	Yes	Significant skills retention was found after 6 months. No randomization of sequence
Kristensen and colleagues[28]	Descriptive	Humans	n.a.	n.a.				Method as for Kristensen[18]	Yes	
Campbell and colleagues[29]	Palpation study, with US as reference method	Human; 44 patients and staff, 24 females	23	2; n.a.	n.a.	Male 70% Female 19%	100% (by the two observers); n.a.	n.a.	No	
Owada and colleagues[30]	Case report. Pre-induction US of CTM for cricothyrotomy	Human; 1; patient with tracheal displacement	n.a.	1; n.a.	n.a.	n.a.; n.a.	1 of 1=100%; n.a.	n.a.	No	
Parmar and colleagues[31]	Descriptive	Human; 100 volunteers, 52 male and 48 female; mean BMI 23 kg m^{-2}		1; n.a.; n.a.	Hyperechoic band	n.a.; n.a.	n.a.; n.a.	Longitudinal and parasagittal	No	
Lamb and colleagues[12]	Palpation study, with US as reference	Human; 12 subjects, 6 men and 6 women; 3 obese in each group, with BMI 30.1–38 kg m^{-2}	41	1; n.a.		Men: non-obese 72%, obese 39%; women: non-obese 24%, obese 35%		Longitudinal, guidewire slid between transducer and skin to identify upper and lower border of CTM	No	
Kristensen and colleagues[11]	Palpation *vs* US, randomized crossover	Human; 1 female; BMI 45.3 kg m^{-2}	35	35; e-learning, 20 min lecture, 20 min hands on	n.a.	37%; 18 s, median	83%; 48 s, median	Same longitudinal approach as described by Kristensen[18]	Yes	
Siddiqui and colleagues[32]	Randomized to palpation or US for percutaneous cricothyrotomy with trocar device	Cadaver; 47; 28 female and 19 male	47	24; 10 min lecture, 3 min video, and 5 times hands on	n.a.	Identification and trocar cricothyrotomy: 39.1%; mean 110.5 s	Identification and trocar cricothyrotomy: 62.5%; mean 196.1 s,	Same longitudinal approach as described by Kristensen[18]	Yes	injury to larynx reduced from 73.9 to 25% in the US group

Continued

Table 1 *Continued*

Publication	Study design	Subjects (human, cadaver, or manikin); *n*; characteristics	Physicians identifying the CTM (*n*)	Physicians who performed the US (*n*); US training for the study	Description of the US appearance of CTM	Identification of CTM by palpation (success rate; duration)	Identification of CTM with US (success rate; duration)	US technique for identification of the CTM	Technique described in detail for replication and applicable without palpable landmarks (yes/no)	Comments
You-Ten and colleagues[13]	Palpation study, with US as reference	Human; 56; women in labour, 28 non-obese and 28 obese, mean BMI 39.2 kg m^{-2}	41	1; trained in neck US	n.a.	71% non-obese women, 39% obese women; obese 23 s, non-obese 12 s, median	(100% by the expert sonographer)	Same longitudinal approach as described by Kristensen[18]	Yes	
Bair and colleagues[33]	Comparing three different clinical methods, with US as reference	Human; 50; mean BMI 28 kg m^{-2}	49	1; n.a.	n.a.	Palpation 62%, four finger widths 46%, visually identifying overlying skin crevasses 50%; 5–45 s (range)	1 of 1=100%	Not described	No	
Yildiz and colleagues[34]	Palpation *vs* US	Humans; 24 volunteers; mean BMI 23.8 kg m^{-2}, mean age 24 yr	5	5; brief training to detect the CTM	n.a.	66.7%; 8.3 s (7.3–9.1), mean (95% CI)	69.2%; 17 s (15.3–18.7), mean (95% CI)	Parasagittal and transverse scan. Relies on being able to identify initially with palpation	No	The sequence was not randomized
Kristensen and colleagues[35]	Descriptive	Humans; n.a.; n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	Longitudinal as described by Kristensen;[18] transverse as in Barbe and colleagues[21]	Yes	
Votruba and colleagues[36]	Descriptive	Humans	n.a.	n.a.	'A hyperechogenic membrane'	n.a.	n.a.	Median or paramedial sagittal view	No	
Stafrace and colleagues[38]	Descriptive, paediatric airway in US	Humans (children)	n.a.	n.a.	n.a.	n.a.	n.a.	Sagittal midline		

guided marking of the cricothyroid membrane is unaffected by changing neck positions (e.g. markings made in the extended-neck position before head manipulation to intubate the trachea accurately identify the cricothyroid membrane also after the intubation attempt when the head and neck are repositioned in extension); and (v) after learning ultrasound-guided techniques, significant retention of skills exists after 6 months.

The studies also give us insight into what type of training is necessary in order to achieve clinically useful success rates in ultrasound-airway-naïve clinicians. We saw success rates in human subjects ranging from 69.2%[34] after 'brief surgical airway anatomy and ultrasonography training' to 100% after 'theoretical airway ultrasonography and 15 min hands-on training'.[21] A 1 h structured lesson that consisted of e-learning, a lecture, and hands-on training resulted in clinically useful 84–90% success in morbidly obese females[11 37] (100% with at least one of two techniques applied).[37]

For some of the described methods, it was a prerequisite that the laryngeal and tracheal structures be identified first with palpation before placement of the ultrasound transducer, whereas other techniques allowed identification of the necessary structures by ultrasound guidance alone without the need for previous clinical identification of laryngeal and tracheal structures. Some studies described their ultrasound technique for identification of the cricothyroid membrane in sufficient detail to allow the method to be reproduced by clinicians, whereas other studies did not. This is summarized in the second column from the right in Table 1.

In order to advocate a clinically useful approach, we reviewed each publication to ascertain whether the ultrasonographic technique described fit the following criteria: (i) could be applied even when tracheal or laryngeal landmarks could not be identified by inspection or palpation alone; (ii) the technique was described in sufficient detail to allow reproduction by other clinicians; (iii) demonstrated a higher success rate than palpation in at least one comparative study; and (iv) published in more than one peer-reviewed indexed publication. Only two techniques fitted the criteria, namely the 'transverse'[20 21 37] and the 'longitudinal'[11 13 18 28 32 37] techniques, and they are outlined in further detail below.

What equipment does one need? Airway ultrasonography can be performed with a standard laptop-sized ultrasound machine. A standard linear high-frequency probe, such as the one most often used for regional anaesthesia and vascular access, will be sufficient.[28]

Performing the transverse technique (for mnemotechnical reasons, we name this the 'TACA' technique ('Thyroid cartilage–Airline–Cricoid cartilage–Airline'))

(i) The transducer is placed transversely on the anterior neck at the estimated level of the thyroid cartilage, and the transducer is moved until the thyroid cartilage is identified as a hyperechoic triangular structure (Fig. 1).

(ii) The transducer is then moved caudally until the cricothyroid membrane is identified; this is recognizable as a hyperechoic white line resulting from the echo of the air–tissue border of the mucosal lining on the inside of the cricothyroid membrane, often with parallel white lines (reverberation artefacts) below.

(iii) The transducer is then moved further caudally until the cricoid cartilage is identified (a 'black lying C' with a white lining).

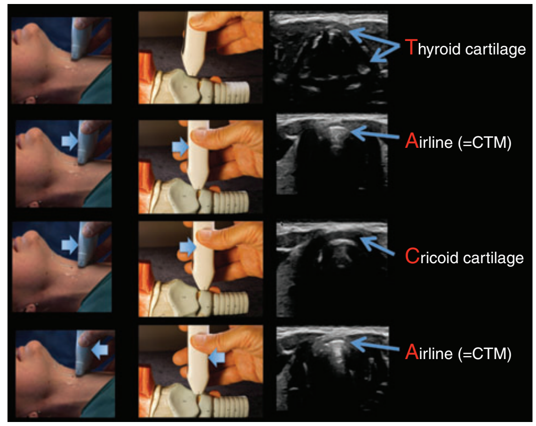

Fig 1 The transverse ('Thyroid cartilage–Airline–Cricoid cartilage–Airline=TACA') method for identification of the cricothyroid membrane. First row: the transducer is placed transversely on the neck where the thyroid cartilage is thought to be until the triangular shape of the thyroid cartilage (=the 'T') is identified. Second row: the transducer is moved caudally until the 'Airline' (=the 'A') is seen; this is the hyperechoic (white) line from the tissue–air border on the luminal side of the cricothyroid membrane. The white line has similar echo lines deep to it; those are reverberation artefacts. Third row: the transducer is moved further caudally until the cricoid cartilage (=the 'C') is seen as a black lying 'C' with a posterior white lining. The white lining represents the tissue–air border on the luminal side of the anterior part of the cricoid cartilage. Forth row: subsequently, the transducer is moved a few millimetres back in the cephalad direction, and the approximate centre of the 'Airline' (=the 'A'=the cricothyroid membrane) is thus identified and can be marked with a pen.

(iv) Finally, the transducer is moved slightly back cephalad until the centre of the cricothyroid membrane is identified.

(v) The location of the cricothyroid membrane can be marked both transversely and sagittally on the skin with a pen. By identifying the highly characteristic shapes of both the thyroid and the cricoid cartilages, both the cephalad and caudal borders of the cricothyroid membrane can be identified.

The technique is demonstrated in this video: http://airwaymanagement.dk/taca.[39]

Performing the longitudinal technique (for mnemotechnical reasons, we name this the 'string of pearls' technique)

(i) The sternal bone is palpated, and the ultrasound transducer is placed transversely on the patient's anterior neck cephalad to the suprasternal notch to see the trachea (horseshoe-shaped dark structure with a posterior white line; Fig. 2).

(ii) The transducer is slid towards the patient's right side (towards the operator), so that the right border of the transducer is positioned over the midline of the trachea, and the ultrasound image of the tracheal ring is thus truncated into half on the screen.

(iii) The right end of the transducer is kept in the midline of the trachea, whilst the left end of the transducer is rotated 90 degrees into the sagittal plane, resulting in a longitudinal scan of the midline of the trachea. A number of dark (hypoechoic) rings will be seen anterior to the white hyperechoic line

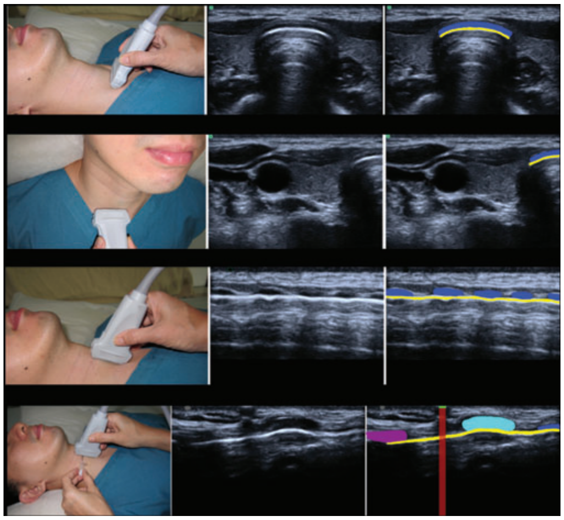

Fig 2 Upper row: step (i) The patient is lying supine, and the operator stands on the patient's right side facing the patient. The sternal bone and the suprasternal notch are palpated, which can be done in even the morbidly obese patient. The linear high-frequency transducer is placed transversely over the neck just cranial to the suprasternal notch, and the trachea is seen in the midline. The middle and the right photographs show the ultrasound image, and the relevant structures are highlighted on the photograph to the right. Blue is the anterior part of a tracheal ring. Yellow indicates the tissue–air boundary inside the trachea. Everything below the tissue–air boundary is artefact. Second row: step (ii) The transducer is slid laterally towards the patient's right side, until the midline of the trachea is at the right border of the transducer, and the corresponding ultrasound image of the trachea (in the right photograph) is truncated into half. Blue is the anterior part of a tracheal ring. Yellows indicate the tissue–air boundary inside the trachea. Third row: step (iii) Staying midline with the right edge of the transducer, the left edge of the transducer is rotated into the sagittal plane to obtain a longitudinal image of the trachea. The anterior parts of the tracheal rings appear as black hypoechoic round structures (like pearls) lying on a strong hyperechoic white line, which is the tissue–air boundary (that looks like a string). Hence, the image is akin to a 'string of pearls'. The blue markings represent the anterior parts of the tracheal rings. Yellow indicates the tissue–air boundary inside the trachea. Fourth row: step (iv) The transducer is slid cephalad, and the anterior part of the cricoid cartilage (turquoise) is seen as a slightly elongated structure that is significantly larger and more anterior than the tracheal rings (blue). Yellow indicates the tissue–air boundary inside the trachea. Immediately cephalad to the cricoid cartilage is the cricothyroid membrane. The distal part of the thyroid cartilage (purple) is seen. Step (v) The cricothyroid membrane can be pointed out by sliding a needle (used only as a marker) underneath the ultrasonography transducer from the cranial end until it casts a shadow (red line) between the cricoid cartilage (turquoise) and the thyroid cartilage. The green spot represents the reflection from the needle. Care is taken not to touch the patient with the sharp tip of the needle. Step (vi) After this, the transducer is removed, and the needle indicates the mid-level of the cricothyroid membrane. This spot can be marked with a pen so that it remains easily identified should it be needed for subsequent difficult airway management. (The figure in the last row is from Kristensen and colleagues).[11]

(air–tissue border), akin to a 'string of pearls'. The dark hypoechoic 'pearls' are the anterior part of the tracheal rings.

(iv) The transducer is kept longitudinally in the midline and slid cephalad until the cricoid cartilage comes into view (seen as a larger, more elongated and anteriorly placed dark 'pearl' compared with the tracheal rings). Further cephalad, the distal part of the thyroid cartilage can also be seen.

(v) Whilst still holding the ultrasound transducer with the right hand, the left hand is used to slide a needle (as a marker, for its ability to cast a shadow in the ultrasound image) between the transducer and the patient's skin until the needle's shadow is seen midway between the caudal border of the thyroid cartilage and the cephalad border of the cricoid cartilage.

(vi) Now the transducer is removed; the needle marks the centre of the cricothyroid membrane in the transverse plane, and this can be marked on the skin with a pen.

The technique is demonstrated on this video: http://airwaymanagement.dk/pearls.[40]

Each of these two techniques functions well individually and has its own advantages.[21 37] For example, not all patients have enough space in the neck to apply the ultrasound transducer in a longitudinal mid-sagittal position (e.g. short neck or severe neck flexion deformity). Here, the transverse technique will be the saviour of the day, and it is the faster of the two techniques. The longitudinal technique, in contrast, can reveal additional information compared with the transverse technique (i.e. the localization of the cricotracheal interspace and of the tracheal interspaces). Apart from the ability to identify overlying blood vessels and direct the clinician to choose another tracheal interspace for elective tracheostomy or retrograde intubation,[41] the longitudinal technique is useful in airway rescue situations where emergency access via the trachea would be needed instead of access via the cricothyroid membrane (e.g. in smaller children,[42 43] in patients with tumours overlying the cricothyroid membrane, and if subglottic obstruction occurs). We recommend that clinicians learn and be proficient in both the transverse and longitudinal techniques because each ultrasound technique can address the other's shortcomings and supplement each other synergistically when used in tandem to be a powerful bedside point-of-care tool.

Clinical impact

Before initiating airway management, the potential ease or difficulty of performing cricothyrotomy[5] and tracheostomy[2] should be evaluated, and an attempt should be made to identify the cricothyroid membrane.[3 44 45] The pre-anaesthetic identification of potentially difficult or even impossible cricothyroid membrane access may direct the clinician towards a more conservative approach, such as awake intubation or awake elective tracheostomy under local anaesthesia. Ultrasound-guided cricothyrotomy may result in significantly less tracheal damage[32] and higher success rates, and ultrasonography should preferably be used to identify the cricothyroid membrane before commencing any airway management, instead of waiting until an emergency airway crisis situation arises.[32]

Based on the recommendations above and the findings discussed in this paper, we recommend the following approach. The cricothyroid membrane should be identified in all patients before induction of anaesthesia and in all patients with airway compromise if time allows. The initial approach is inspection. Just by looking for the creases on the anterior neck, the cricothyroid membrane can be identified rapidly in approximately half of patients.[33] If inspection fails, then palpation should be performed, and if this also fails or any doubt exists, then ultrasonographic identification should be performed. All anaesthesia departments or anaesthesia services should aim at being able to deliver this service. The cricothyroid membrane should also be identified before extubation of a difficult airway so that it is available for emergency airway access in case of a failed extubation with subsequent difficult reintubation.

In emergency airway management, time is of utmost importance. However, urgency is relative, and in an impending (incomplete or partial) or progressive airway obstruction, there is a time window for meaningful interventions, such as optimized pre-oxygenation, collation of equipment, and formulation of a plan for airway management, including a plan for failure. In the NAP4[7] study, in at least 18 of 58 patients where a surgical airway was attempted after failed intubation, it was still possible to ventilate by face mask or by a supraglottic airway device, and in such patients there will be sufficient time for performing ultrasonography for identification of the cricothyroid membrane, in tandem with other preparations and attempts at maximizing pre-oxygenation, provided that the clinician is proficient in its use and that an ultrasound machine is readily available.

Authors' contributions

Study design, protocol conceptualization and literature selection: M.S.K., W.H.T.
Literature search: M.S.K.
Writing of the manuscript: M.S.K., W.H.T., S.S.R.

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Seeing is believing: getting the best out of videolaryngoscopy

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Almost half of all incidents reported to the 4th National Audit Project (NAP4) of the Royal College of Anaesthetists and the Difficult Airway Society (DAS) described airway complications that followed primary problems with intubation, including failed tracheal intubation, delayed tracheal intubation, and 'can't intubate can't oxygenate' (CICO) situations.[1] In addition, considerably more than half of the incidents reported to NAP4 involved problems with intubation as the airway incident progressed.[1] The recently published DAS 2015 guidelines emphasize the importance of the first attempt at laryngoscopy, with the aim of Plan A being to 'maximize the likelihood of successful intubation at first attempt, or failing that, to limit the number and duration of attempts at laryngoscopy, to prevent airway trauma and progression to a CICO situation.'[2] It is recognized that a suboptimal attempt at laryngoscopy is a 'wasted attempt' and that, if intubation fails, the chance of success declines with each subsequent attempt at laryngoscopy.[2–4] The importance of first-pass success is arguably even greater in the critically ill patient, when multiple attempts at intubation lead to high rates of severe hypoxia and other life-threatening (or life-ending) complications.[5]

Benefits of videolaryngoscopy

Videolaryngoscopy is undoubtedly one of the major advances in practical anaesthesia in recent years. At present, the main challenges are to determine to what extent it should penetrate routine clinical practice and to determine which devices are best. The progression from standard Macintosh laryngoscopes to videolaryngoscopes has been likened to the advance from standard mobile cell phones to smart phones.[6] Several editorialists have called for videolaryngoscopy to be a first-line technique for airway management.[7–10] Importantly, the role of videolaryngoscopy in difficult intubation has recently been recognized in the DAS 2015 guidelines, which recommend that all anaesthetists are trained in videolaryngoscopy and that all anaesthetists have immediate access to a videolaryngoscope at all times.[2] Videolaryngoscopy has been recommended for intubating obese patients,[3 11 12] a group known to have a higher risk of complications associated with airway management.[1 2] Beyond anaesthesia, predictions have been made that videolaryngoscopy will dominate the field of emergency airway management in the future.[4 7 13] It seems that cost is the main consideration holding back the tide.[7 9]

There are many reasons for such enthusiasm. Firstly, there are numerous technical benefits. Videolaryngoscopy gives the user a better view of the larynx than with a standard Macintosh laryngoscope (direct laryngoscopy).[2 6–8 12] This improved laryngeal view is the result of two factors: for videolaryngoscopes with Macintosh-shaped blades, a camera on the distal end of the blade gives an increased field of view compared with direct laryngoscopy, whereas for videolaryngoscopes with extra-curved blades, this increased field of view is augmented by the capacity to 'see around the corner' and gain a view of structures that are beyond the reach of Macintosh-style blades.[6] This improved view of the larynx is seen even with only minimal head and neck manipulation.[7 12]Appropriately chosen videolaryngoscopes are therefore beneficial for the management of both anticipated and unanticipated difficult laryngoscopy.[7 14 15] The force required when intubating with a videolaryngoscope is less than that required for direct laryngoscopy, resulting in less risk of trauma to soft tissues and teeth,[14 16–19] and a reduced incidence of sore throat.[18 19] Several videolaryngoscopes have a higher rate of successful intubation when used as a rescue device when direct laryngoscopy fails.[2 20–22] As most difficult intubations are not anticipated,[14 15] first-line use of videolaryngoscopy not only reduces the risk of difficulty, but, when this occurs, eliminates the need for the intubator to swap to another device when time and oxygenation are critical. The number of attempts at laryngoscopy can be kept to a minimum, and it is highly likely that unanticipated difficult intubation would be less frequent if videolaryngoscopes were used as a first-line technique.[7]

Secondly, there are significant training advantages associated with using videolaryngoscopes, though perhaps restricted to videolaryngoscopes that have a remote screen rather than one attached to the laryngoscope handle. When the trainer can observe the larynx on a screen while the trainee performs laryngoscopy, the trainer can help the trainee to optimize the blade position and advise the trainee on where to place the tracheal tube by pointing out necessary landmarks on the screen.[9] As the view of the larynx can be seen by trainee and trainer, and the technique can be optimized in real time, it is more likely that a trainee will be able to complete an intubation themselves without the trainer taking over.[23] This is especially useful for rapid sequence inductions and in patients at risk of hypoxia.[9] Whether the trainee is 'allowed' to see the screen or simply to use the videolaryngoscope for direct laryngoscopy (with reference to the screen only if difficulties are encountered) can be decided according to training aims. Five studies have now demonstrated that training novice intubators in direct laryngoscopy is more effective when the trainee uses a videolaryngoscope rather than a standard Macintosh laryngoscope.[7 9 24–27]

Thirdly, there are non-technical or human factors advantages associated with videolaryngoscopy, again seen best with devices that have a separate screen. The whole team can see the view of the larynx, improving teamwork and communication. The anaesthetic assistant can see when the intubator is struggling much earlier and can anticipate the 'next step', ensuring that the necessary equipment is immediately to hand.[7 9 23 26 27] When applying cricoid force, the anaesthetic assistant can assess whether this is improving the view of the larynx or, conversely, displacing or even compressing the larynx and making the view worse, and can immediately adjust the direction and degree of cricoid force as necessary.[23 26] Videolaryngoscopes can help trainee anaesthetic assistants to learn how to perform cricoid pressure, with their supervisor directly supervising them and helping them to adjust it as needed. The fact that the whole team can see the tracheal tube pass through the vocal cords, rather than only the intubator, provides clinical governance advantages. One author has described this as 'multi-person visualisation'.[7] In our experience, it simply changes difficult airway management from 'I' to 'we'.

Fourthly, the ability to record the intubation as a 'digital airway record' has advantages. It may be useful for training (to review with a trainee at leisure) or as part of the medicolegal records.[6 28] New medical diagnoses, such as vocal cord malignancies, have also been made with use of videolaryngoscopy during training.[29]

Finally, emerging evidence hints at benefits for the anaesthetist in addition to the patient. Grundgeiger and colleagues[30] demonstrated an improvement in the intubator's 'total body position' when using videolaryngoscopy compared with direct laryngoscopy.

As described, these advantages are likely to be even more important when intubating critically ill patients, such as in the intensive care unit, where airway management is especially high risk.[5 31 32] In the NAP4 report, complications of airway management were up to 60 times more likely to occur in the intensive care unit than in the operating room, and when they happened they were more likely to result in death or brain injury (61%) than incidents occurring in the operating room (14%).[33]

Types of videolaryngoscope

There are now a large number of videolaryngoscopes available, with the number constantly increasing and many existing devices being modified. Although this can create a confusing picture, the devices can be broadly classified into the following three groups: (i) devices with a Macintosh-like blade, such as AP Advance (Venner Medical International, St Helier, Jersey, UK), C-MAC (Karl Storz Endoscopy, Slough, Berkshire, UK), GlideScope MAC (Verathon Medical, Bothwell, WA, USA), and McGrath Mac (Aircraft Medical, Edinburgh, UK); (ii) devices with an extra-curved blade, such as AP Advance with difficult airway blade (Venner Medical), C-MAC D blade (Karl Storz Endoscopy), GlideScope (Verathon Medical), King Vision with standard blade (Ambu, St Ives, Cambridgeshire, UK), and McGrath Mac with curved blade (Aircraft Medical); or (iii) devices with a channelled blade (conduited VL), such as Airtraq (Teleflex, Morrisville, NC, USA), Pentax AWS (Ambu), and King Vision (Ambu).

It is highly likely that not all videolaryngoscopes are equal, and it is therefore important to understand which videolaryngoscopes perform better than others.[34] However, the current evidence base has focused on comparing videolaryngoscopy with direct laryngoscopy, and there is little high-quality evidence regarding the relative performance of different videolaryngoscopes at present. Mihai and colleagues[35] published a meta-analysis in 2008, but were unable to draw clear or useful conclusions regarding which performed best, reporting that most studies were of poor quality and that the vast majority of studies did not include truly difficult patients. A Cochrane meta-analysis on the topic is in progress.[36] Manikin studies and numerous small patient studies shed little light on the topic, and there are no large randomized controlled trials to date. Co-ordinated efforts to collect comparative clinical data would help to guide implementation.

Clinical pearls in videolaryngoscopy

Despite the many advantages described here, there are potential pitfalls that may be encountered when using videolaryngoscopy, most of which are readily avoided with care and knowledge. We propose the following 'rules of videolaryngoscopy' to help maximize the benefit the intubator can gain from using these devices.

Rule 1: experience with a standard Macintosh laryngoscope does not equate to skill with a videolaryngoscope

The technique for videolaryngoscopy (particularly with extra-curved and conduited blades) differs from that for direct laryngoscopy, and manufacturers' recommended techniques for many videolaryngoscopes differ from each other. This has important implications. Experienced anaesthetists, skilled at intubation using a Macintosh laryngoscope, cannot expect to be able to use a videolaryngoscope effectively without training and practice. Although some reports describe very short learning curves,[7 27] Lafferty and colleagues[15] reported that 76 intubations with a GlideScope were needed to achieve competence.[37] The 2015 DAS guidelines emphasize the need for all anaesthetists to be trained in the use of videolaryngoscopes. Given that trainee anaesthetists rotate to different hospitals, they will also need to be trained fully in the videolaryngoscope(s) available at each hospital.[2] This is likely to require an increase in formal training in these techniques.

Of note, videolaryngoscopes with a Macintosh-type blade can be used for both direct laryngoscopy and videolaryngoscopy and do use a similar technique, giving them an important advantage for training. The videolaryngoscope blade is inserted into the oral cavity using the standard direct laryngoscopy technique, and the glottis can then be seen either under direct vision or on a video screen.

Rule 2: experience with one type of videolaryngoscope does not equate to skill with all videolaryngoscopes

There are numerous different designs of videolaryngoscopes, and several require different techniques for use.[35] For example, the C-MAC is designed to be used as a standard Macintosh laryngoscope, while the GlideScope is inserted along the centre of the tongue without the need for tongue displacement.[7] Insertion depth and direction of applied forces for the Airtraq and many extra-curved videolaryngoscopes differ markedly from direct laryngoscopy. These devices generally need to be inserted less far and require the blade to be lifted vertically once it is in the correct position, rather than along the axis of the laryngoscope handle, as with direct laryngoscopy. This again has implications for training and patient safety. Research to establish which videolaryngoscopes perform best would reduce this burden and, in the meantime, hospital networks may decide to unify choice of videolaryngoscopes to minimize training needs.

Rule 3: a good videolaryngoscopic view of the vocal cords does not guarantee easy intubation

This is true for all videolaryngoscopes,[7 15 31] but especially true for videolaryngoscopes with extra-curved and channelled blades.

Lafferty and colleagues[15] reported that 'gaining a view of the vocal cords "is the easy part"' when using a videolaryngoscope. Training, regular practice, and use of device-specific adjuncts are required to ensure that an improved view of the larynx translates reliably into successful tracheal intubation.[2 38]

Extra-curved blades deliver an improved view of the larynx but also prevent direct visualisation of the larynx, which is one reason why they are useful for difficult intubations but slow down easy intubations. These devices require routine use of an intubating adjunct to deliver the tip of the tracheal tube to the larynx. Inexpert use of these devices may lead to intubation failure and airway trauma.[39] Some manufacturers specifically recommend and supply bespoke stylets.[40] However, use of stylets has perhaps fallen out of fashion in many countries, and poor use of stylets, particularly around the 'blind spot' found when using extra-curved videolaryngoscopes, may increase the risk of trauma during intubation.[39 41] New skills may be needed to use such stylets safely and effectively.[15] Other cost-effective options include tubes and stylets that can be flexed dynamically during intubation.[42–45]

Conduited devices with a channelled blade require not only 'a view of the larynx' but an 'optimal view of the larynx' because only this ensures that the tracheal tube is directed correctly through the guide channel towards the larynx. A partial or non-optimal view will lead to the conduit reliably directing the tube away from the larynx. These devices also require a tube of appropriate type and size for a given conduit for intubation to succeed.[46]

Rule 4: a bougie may not be the solution when there is difficulty

Although many anaesthetists will be familiar with using a bougie for assisting direct laryngoscopy, and its use with videolaryngoscopy has been advocated,[47 48] there are limitations to this technique. When using an extra-curved videolaryngoscope, the bougie has a tendency to uncurl during passage towards the larynx, leading to failure; this is particularly true when using modern disposable bougies, which often lack the plasticity ('memory') of the original gum elastic bougie.[49] The curvature of the tracheal tube may be maintained to match the shape of the blade with a curved stylet.[15 50–53]

A particular problem with a conduited videolaryngoscope is that, because of the small diameter of a bougie, it tends to cut across the curve of the conduit and pass posteriorly (as do smaller than intended tracheal tubes).[44] Perhaps counterintuitively, sometimes the solution to a posteriorly passing tracheal tube with a conduited device may be to change to a larger tracheal tube or smaller laryngoscope, both of which tend to increase anterior curvature of the tube during passage.

Rule 5: the videolaryngoscope chosen must be selected according to indication

There is little evidence about which device should be chosen for which situation;[7] however, we offer the following practical advice.

If a videolaryngoscope is being chosen to use as a rescue device when intubation with direct laryngoscopy is unsuccessful, it would be advisable to choose a videolaryngoscope with an extra-curved blade (with or without a conduit), which increases the chance of seeing 'round the corner' in this situation.

If, however, a videolaryngoscope is being used for training purposes (especially to train novices in direct laryngoscopy), we would suggest choosing one with a Macintosh-shaped blade, because direct laryngoscopy cannot be taught appropriately with an extra-curved device and such training is supported by evidence.[7 9 24–27] It would also be advisable to choose a videolaryngoscope with a screen separate from the laryngoscope handle in this situation, because this makes it easier for the trainer to observe the actions of the trainee and also enables teaching of other members of the theatre team.

If a videolaryngoscope is being used for general everyday practice, it may be best to choose a videolaryngoscope which has the option of using both a Macintosh-shaped blade and an extra-curved blade; at present, videolaryngoscopes from the manufacturers Aircraft Medical, Storz, Venner, and Verathon all provide both options.

If a videolaryngoscope is being used in a prehospital setting, a device where the screen is attached to the laryngoscope handle and one that has a screen that is visible in direct sunlight is likely to be more practical. Such devices include the Airtraq with iphone attachment, AP advance, C-MAC Pocket Monitor, King-Vision, McGrath Mac, and Pentax AWS.

If a videolaryngoscope is being used when there is blood in the airway or when the airway is heavily soiled, a videolaryngoscope that can be used for both direct laryngoscopy and videolaryngoscopy may be the most appropriate. The videolaryngoscope camera may become fogged or obstructed in this situation, but the operator may then fall back on the direct laryngoscopy function if necessary.[10]

Bearing in mind the advantages listed above, we agree with other authors that there is now a robust argument for videolaryngoscopy to be used for all intubations.[6 9 10] If videolaryngoscopy were used for all patients, experience and skill with the techniques would undoubtedly increase, and the evidence would suggest that the number of attempted intubations would decrease, complications of multiple attempts at intubation would reduce, and patient care would improve. The biggest impediment to this is likely to be cost.[6 9] However, when the costs of managing the delays, alternative techniques, and complications of difficult or failed intubation are considered, the gap is not as large as might be expected.[54]

In summary, videolaryngoscopy is a potential step change advance in anaesthesia, but its introduction needs to be accompanied by appropriate training of all anaesthetists; not only trainees, but also trained and experienced intubators. The potential benefits of videolaryngoscopy for patients are numerous and significant.

Authors' contributions

Preparation of first draft of manuscript and subsequent review of manuscript: F.E.K.
Review of manuscript: T.M.C.

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Declaration of interest

None declared.

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Is it time for airway management education to be mandatory?

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Complications secondary to airway management in anaesthesia are relatively rare but when they do occur, the causal and contributory factors are often attributed to human error related to inadequate training and poor judgement by the anaesthetist.[1] These complications continue to occur despite competency-based medical education curricula and detailed practice guidelines.

One criticism of competency-based medical education is that it applies primarily to trainees and focuses too much on the

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Paediatric difficult airway management: what every anaesthetist should know!

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Airway management remains a significant cause of morbidity and mortality in anaesthetized children. Children with difficult direct laryngoscopy are an especially vulnerable group. However, most paediatric anaesthetics are administered by generalists without advanced paediatric training. This editorial is aimed at all practitioners who care for children, particularly those without advanced paediatric anaesthesia training. Our goal is to convey three important points: (i) the contributing factors for severe complications in this population; (ii) the important role of the supraglottic airway (SGA) in managing these patients; and (iii) the ideal method of invasive airway access when oxygenation is compromised. We hope this editorial enhances the care and outcomes in this vulnerable patient population.

The paediatric difficult airway is associated with a high risk for complications during airway management

A multicentre study of 1018 children with difficult airways in 13 paediatric centres (Pediatric Difficult Intubation registry) demonstrated that more than two direct laryngoscopy attempts in children with difficult tracheal intubation is associated with high failure rates and an increased incidence of severe complications.[1] In fact, every additional attempt beyond the first increased the proportion of patients with complications. This extensive study was the first to confirm that airway management in a paediatric difficult airway population cared for mostly by paediatric anaesthetists is associated with significant complication rates. In these children, tracheal intubation failed in 19 (2%) patients, and 204 (20%) children had at least one complication. The most common severe complication was cardiac arrest, which occurred in 2% of these children. The most common complication overall was transient hypoxaemia (oxygen saturation <85%). The results of this study should prompt anaesthetists caring for children to consider the following strategies: (i) minimize the number of direct laryngoscopy attempts, and transition to an indirect technique (videolaryngoscope/fibreoptic bronchoscope) when direct laryngoscopy fails; and (ii) consider a means for oxygenation of the lungs during tracheal intubation attempts (nasal cannula or supraglottic airway) to reduce the risk of complications and enhance patient safety. Lastly, this study also identified the following four independent risk factors that are associated with the increased risk of complications: more than two tracheal intubation attempts; weight less than 10 kg; short thyromental distance (micrognathia); and three direct laryngoscopy attempts before an indirect technique.[1]

Supraglottic airways for the difficult airway: what is the evidence?

Use of an SGA is a distinctive step in many airway management algorithms.[2–4] An SGA may be used in situations where difficult ventilation, failed intubation, or both occur. The paediatric airway guidelines published by the Difficult Airway Society/Association of Paediatric Anaesthetists of Great Britain and Ireland suggests the use of an SGA, if feasible, when failed tracheal intubation occurs in children with difficult airways.[5] In the paediatric practice, general anaesthesia is often required for brief procedures (e.g. radiology, ophthalmological, or general surgery) which would typically not need any form of anaesthesia in adults. For these procedures, it may not always be necessary to intubate the trachea. In children with difficult airways, an SGA alone can be used to provide an adequate airway with low failure rates and should be considered for airway maintenance in this population.[6] Additionally, in the paediatric population, the SGA failure rate is lower than in the adult population (0.86[7] *vs* 1.1%[8]). Supraglottic airway failure in children is more likely in the presence of the following risk factors: ear/nose/throat surgery, inpatient procedures, prolonged surgical duration, congenital/acquired airway abnormalities, and patient transport.[7] Although these risk factors for failure have been identified, clinicians should have sufficient experience with the routine use of these devices and know how to recognize and troubleshoot causes for inadequate ventilation of the lungs, such as improper position or fit, and should remain vigilant for subtle signs of poor device performance.[9] Additionally, all equipment necessary to perform tracheal intubation should be readily on hand and checked in the unlikely event that tracheal intubation is needed. Supraglottic airways have been very useful as a conduit for tracheal intubation in children with difficult airways.[10 11] Future analysis of the multicentre Pediatric Difficult Intubation registry may help to answer questions about the efficacy of SGAs in specific difficult airway populations; for instance, is fibre-optic tracheal intubation through an SGA superior to using a videolaryngoscope in the Pierre Robin infant?

'Cannot intubate, cannot oxygenate' in an infant: invasive airway access in children

The need for an emergency surgical airway in infants is very rare. Most anaesthetists may never even encounter this clinical situation in their career, especially in smaller children. There is a dearth of literature regarding invasive airway techniques in this patient population, and very little equipment development in this area. Most studies to date incorporate the use of rabbit[12 13] or pig models.[14 15] Moreover, the cricothyroid membrane is difficult to identify in this age group, and expeditious performance of a surgical airway is challenging even for a skilled paediatric otolaryngologist. In a crisis, therefore, the fastest option to oxygenate the lungs is most likely to be through a needle cricothyroidotomy. However, the use of 14, 16, or 18 gauge angiocatheters for needle cricothyroidotomy is not without risk. Animal studies demonstrate that, although invasive tracheal access may be successful on the first attempt in about 60–70%, placement of the needle is associated with perforation of the posterior tracheal wall.[13 14]

Once a needle cricothyroidotomy is appropriately placed in the trachea (pig model), adequate oxygenation has been demonstrated with a low-pressure oxygen supply (e.g. wall oxygen at 1–15 litres min^{-1}) attached to an Enk Oxygen Flow Regulator (Cook Medical, Bloomington, IN, USA). This technique has been shown to provide effective oxygenation for at least 15 min[16] when oxygen is administered through an 18 gauge or larger diameter angiocatheter.[17]

In the event of complete upper airway obstruction, it has been shown that the Ventrain device (Dolphys Medical, Eindhoven, The Netherlands) may provide adequate oxygenation and ventilation through a small-bore transtracheal catheter.[15] This device may be of use in the 'cannot intubate, cannot oxygenate' situation in an infant but has yet to be studied in the infant animal model.

Lastly, although scalpel cricothyroidotomy is the recommended surgical airway technique in the new Difficult Airway Society airway algorithm for adults,[4] the evidence in children is lacking. One rabbit study demonstrated that the first attempt success rate was 100% but was associated with significant complication rates (posterior tracheal wall damage).[12] More studies on both techniques are still needed to help determine the best practice for smaller children, but currently, needle cricothyroidotomy remains the technique of choice in the 'cannot intubate, cannot oxygenate' situation in infants.[5]

In conclusion, although airway management strategies for children have come a long way during the past few years, with improvements in technique and equipment, management of the difficult paediatric airway still remains a problem associated with significant risks and complications. Future multicentre studies in this high-risk group may help us to determine the best airway practices for these children.

Authors' contributions

Conception and design of the editorial, drafting the article, and final approval of the version to be published: N.J., L.S., J.E.F.

Declaration of interests

N.J. is on the editorial board of *Pediatric Anesthesia* and *Journal of Anesthesia* (Japan). He has received products free of charge from Ambu and Teleflex corporations. He serves on the Medical Advisory board of Teleflex and has received travel support for meetings involving future developments for upcoming airway devices. J.E. F. and L.S.: none declared.

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Airway management in the critically ill: the same, but different

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Airway management has had a central role in intensive care medicine even from its origins. When Danish Anaesthetist Björn Ibsen applied his airway skills to victims of the 1952–3 Copenhagen poliomyelitis epidemic, the era of Critical Care Medicine was born.[1] The

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Special Issue

Transtracheal jet ventilation in the ‘can’t intubate can’t oxygenate’ emergency: a systematic review

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Abstract

Background: Transtracheal jet ventilation (TTJV) is recommended in several airway guidelines as a potentially life-saving procedure during the ‘Can’t Intubate Can’t Oxygenate’ (CICO) emergency. Some studies have questioned its effectiveness.
Methods: Our goal was to determine the complication rates of TTJV in the CICO emergency compared with the emergency setting where CICO is not described (non-CICO emergency) or elective surgical setting. Several databases of published and unpublished literature were searched systematically for studies describing TTJV in human subjects. Complications were categorized as device failure, barotrauma (including subcutaneous emphysema), and miscellaneous. Device failure was defined by the inability to place and/or use the TTJV device, not patient survival.
Results: Forty-four studies (428 procedures) met the inclusion criteria. Four studies included both emergency and elective procedures. Thirty studies described 132 emergency TTJV procedures; 90 were CICO emergencies. Eighteen studies described 296 elective TTJV procedures. Device failure occurred in 42% of CICO emergency vs 0% of non-CICO emergency ($P<0.001$) and 0.3% of elective procedures ($P<0.001$). Barotrauma occurred in 32% of CICO emergency vs 7% of non-CICO emergency ($P<0.001$) and 8% of elective procedures ($P<0.001$). The total number of procedures with any complication was 51% of CICO emergency vs 7% of non-CICO emergency ($P<0.001$) and 8% of elective procedures ($P<0.001$). Several reports described TTJV-related subcutaneous emphysema hampering subsequent attempts at surgical airway or tracheal intubation.
Conclusions: TTJV is associated with a high risk of device failure and barotrauma in the CICO emergency. Guidelines and recommendations supporting the use of TTJV in CICO should be reconsidered.

Key words: airway management; emergencies; respiration, artificial

Transtracheal jet ventilation (TTJV) is the introduction of pressurized oxygen usually through a narrow-bore cannula cricothyroidotomy. 'Narrow-bore cannula' has been variously defined as <4 mm[1] (10 gauge), or <2 mm[2] (14 gauge). While TTJV is sometimes used during elective head and neck procedures, it has also been advocated as a rescue procedure during emergency airway management. Current Difficult Airway Society (DAS) guidelines recommend scalpel cricothyroidotomy as the favored technique in the 'Can't Intubate, Can't Oxygenate' (CICO) scenario. Notwithstanding, TTJV through a narrow-bore cannula cricothyroidotomy is also included in the DAS CICO recommendations, but limited to clinicians experienced with this technique in their routine clinical practice.[1] This recommendation is similar to the Canadian guidelines.[3] The DAS paediatric CICO guidelines include TTJV as an option in children one to eight yr old.[4] The ASA has published difficult airway guidelines over three decades[5–7] and includes TTJV as an option during a CICO emergency. TTJV for the CICO emergency is advocated in Australia[8] and is mentioned as an option in airway guidelines from Germany[9] and Italy.[10]

Some studies have suggested a high incidence of failure and barotrauma with the use of TTJV.[2 11] The National Audit Project 4[2] reported 12 failures in the 19 attempts at narrow-bore cannula cricothyroidotomy with jet ventilation. In a review of airway-related malpractice claims that had reached legal settlement and were registered in the Anaesthesia Closed Claims Project,[11] Peterson reported that of the nine TTJV procedures performed during CICO emergencies, eight were complicated by barotrauma and all had poor outcomes.

Despite its inclusion in many published airway guidelines to manage the CICO emergency, the benefit of TTJV is unclear. Given this uncertainty we performed a systematic review of its use in clinical practice. Our primary goal was to determine the complication rates of TTJV use in the CICO emergency setting and compare them with the complication rates of those occurring in the emergency setting, where CICO is not described (the non-CICO emergency) and the elective surgical settings. Complications were categorized as device (thus technique) failure, occurrence of barotrauma including subcutaneous emphysema, or miscellaneous (e.g., cardiovascular collapse or bleeding). Device failure was defined by the inability to place and/or use the TTJV device and not by patient survival.

Methods

This study was registered with the International Prospective Register of Systematic Reviews February 16, 2015 (Registration #CRD42015016605) and conducted following the Preferred Reporting Items for Systematic review and Meta-Analysis (PRISMA) statement.[12]

Search strategy

We searched the following databases: Medline (1946 - March 2016), EMBASE (1974-March 2016), Cochrane Database of Systematic Reviews, ACP Journal Club, Database of Abstracts of Reviews of Effects, Cochrane Central Register of Controlled Trials, Cochrane Methodology Register, Health Technology Assessment, and the NHS Economic Evaluation Database. Searches were conducted on March 10th 2015 and repeated on August 28th, December 17th 2015, and March 30th 2016.

Search strategies were constructed separately for each source, based on the search interface and a balance of search sensitivity and specificity. The keywords 'transtracheal', 'trans-tracheal', 'cricothyrotomy', and 'cricothyroidotomy' were used for the Cochrane suite of databases and the unpublished literature searches. The keywords 'airway management', 'oxygenat*', and 'ventilat*' were added to the Medline and EMBASE search strategies, along with the subject headings 'airway management' (MeSH) and 'respiration control' (EMTREE) in order to increase search specificity in these databases. The Cochrane and unpublished literature search strategy mirrored the Medline/EMBASE search strategy as closely as possible, by capturing the transtracheal/cricothyrotomy aspect without further limiting the search results. The Cochrane/unpublished literature search strategy has greater sensitivity than the Medline/EMBASE search strategy, without sacrificing the original design and intent for this systematic review. The full search strategies can be found in Appendix 1. Bibliographies from narrative reviews were hand searched for further potential articles.

Unpublished literature

The unpublished literature was searched in the conference abstracts indexed by EMBASE from 1974 to March 2016 (which included the International Anaesthesia Research Society conference abstracts), and through the conference websites, conference journals or personal communication with conference organizers (see Acknowledgements Section) of the inaugural 2015 World Airway Management Meeting, ASA (2000-March 2016), the Canadian Anesthesiologists' Society (2007-March 2016), the Society for Airway Management (2005; 2007-March 2016) and the Difficult Airway Society (2012–2014). Although the last ten yr of society abstracts were requested from these societies, only certain yr were available. The Anaesthesia Closed Claims Project was also searched by written data request to the project administrator. Clinical leaders in the field of airway management were also contacted for abstracts from the above-listed meetings, further documented patients that may not have appeared in either published or unpublished scientific sources, or for clarification of details regarding their publications (see Acknowledgement Section).

Study selection

Independently and in duplicate, two authors reviewed all abstracts. A third author arbitrated disagreements. We included any study that reported at least one human subject of any age undergoing elective or emergency TTJV. As this systematic review is focused on TTJV use in clinical practice, animal, cadaver, mannequin, and lung-modeling studies were excluded. Animal models were excluded because their differing laryngeal and sub-laryngeal anatomy could impact success and complications of TTJV, in both simulated CICO and non-CICO scenarios, compared with humans. Cadaver studies, in both simulated CICO and non-CICO scenarios, were also excluded as many of our study parameters (e.g., occurrence of barotrauma, cardiovascular collapse or bleeding) would not be apparent in such a model. Also excluded were studies examining high-frequency jet ventilation, as this technique is not part of any published airway guideline. Articles were limited to those published in English or French.

Data extraction

We abstracted the following data from the included studies: emergency or elective TTJV, patient characteristics, catheter type, ventilation device and strategy, oxygen-driving pressure and complications. Emergency TTJV was further subdivided into studies describing a CICO emergency, and those where emergency TTJV use occurred without CICO being described.

Complications abstracted included device failure, barotrauma, or other miscellaneous complication(s). Device failure was defined as the failure to place the device in the airway, dislodgment of the cannula from the airway, kinking or breaking of the cannula, or dislodgement of the cannula hub from the oxygenation device.[2] Other complications were categorized as barotrauma of any type (e.g. pneumothorax, pneumomediastinum, subcutaneous emphysema) or other miscellaneous recorded complications (e.g. cardiovascular collapse or bleeding). The total number of procedures with one or more complication was also recorded.

Data synthesis and analyses

We compared the proportion of procedures where the TTJV device failed or complications were described (e.g. barotrauma or not barotrauma) in each of the following three groups: TTJV in CICO emergencies, TTJV in non-CICO emergencies and TTJV use in elective surgery. These groups were compared using Fisher's exact test; a difference between groups of $P<0.05$ defined significance.

Results

Database searching yielded 959 articles. In addition to 15 duplicate citations, 729 articles were excluded on initial abstract screening. From the unpublished literature, nine studies were identified.[2 13–19] In total, 239 studies underwent full text review and 192 were subsequently excluded. Three studies that initially met inclusion criteria were excluded on more detailed review.[20–22] Smith's 1976 study[22] included the identical number of procedures and clinical details as that of his 1975 study,[23] which was included. In two studies by Jacobs,[20 21] TTJV was performed on terminally ill patients with no described indication and no reporting of ethics board approval, therefore these studies were excluded. In total, from both unpublished and published literature, 44 studies (428 procedures) met inclusion criteria (Fig. 1).

Four studies described both elective and emergency procedures,[23–26] therefore the number of studies in each category are not additive. Emergency TTJV was described in 30 studies[2 11 13–19 23–43] totaling 132 procedures. Of the 30 emergency studies, two studies[23 26] included procedures for both CICO and non-CICO indications, therefore the number of studies in each group are not additive. Twenty-three studies[2 11 13–15 17–19 23–26 33–43] (90 procedures) described CICO as the indication for emergency TTJV (Table 1). Nine of the emergency TTJV studies[16 23 26–32] (42 procedures) did not describe CICO as the indication for TTJV (Table 2). TTJV in elective surgery was described in 18 studies[23–26 44–57] totaling 296 procedures (Table 3).

In the 23 studies describing 90 TTJV procedures in CICO emergencies (Table 1), device failure was recorded in 38 (42%), barotrauma occurred in 29 (32%), and miscellaneous complications in 8 (9%). The total number of procedures with one or more complication was 46 (51%). Sixty (67%) of the 90 CICO emergency procedures were found in four[2 11 13 43] of the 23 retrieved studies.

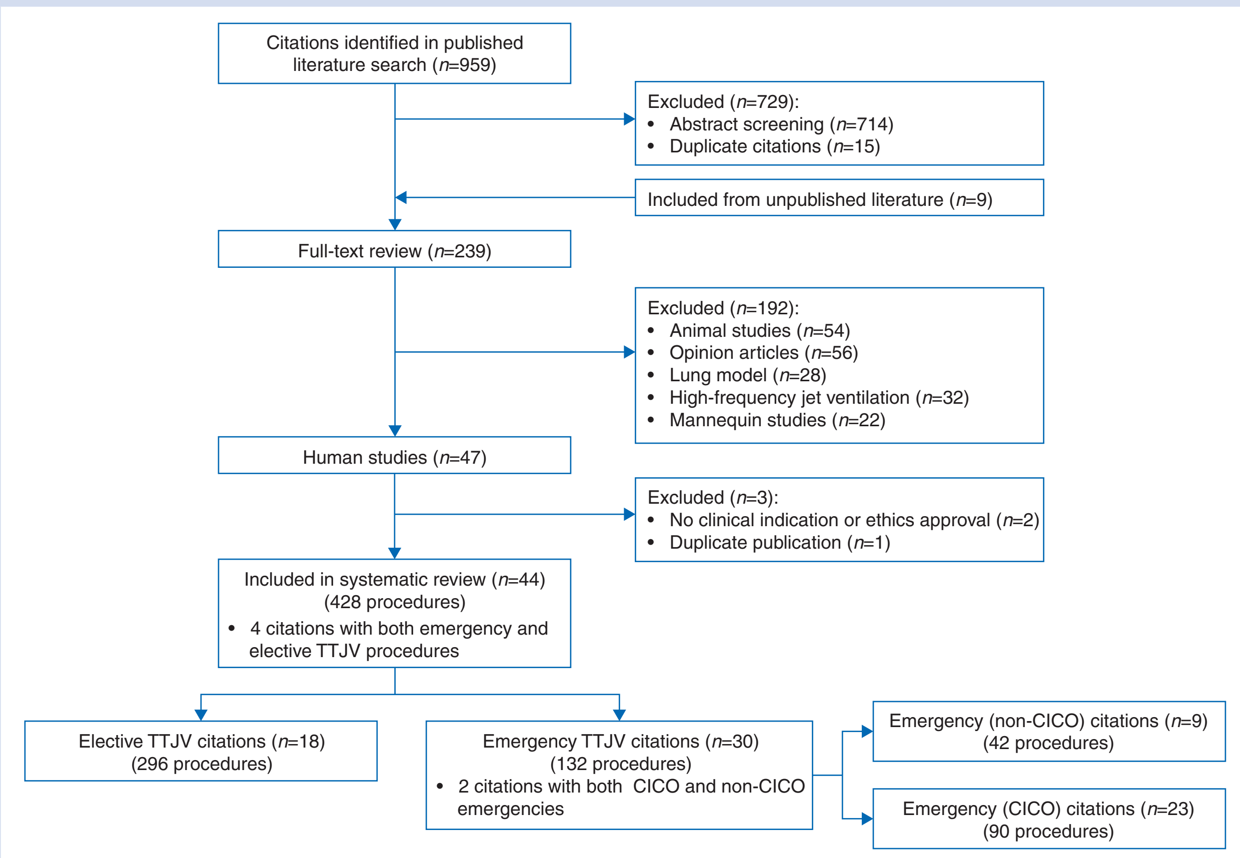

Fig 1 Flow chart of the study.

Table 1 TTJV use in CICO emergencies. ENT, otolaryngology surgery; M, male F, female; g, gauge; kPa, kilopascals; psi, pounds per square inch

Author, Yr (no. of procedures)	Clinical Circumstances	Age, Gender	Cannula size, Type	Oxygenation: Oxygen pressure kPa/psi, jets/min	Complications (#)
Patel, 1999[44] (29)	Intensive care patients, no other details	49–82 M	12 g, 14 g	340 kPa/50 psi, 12–20 jets/min	Device failure (6) Barotrauma (4)
NAP 4[2] (19)	No details	No details	No details	No settings stated	Device failure (12) Barotrauma (6) Difficult tracheal intubation (1)
Peterson, 2005[11] (9)	No details	No details	No details	No settings stated	Device failure (8) Barotrauma (8)
Benumof, 1989[35] (5)	Extubation failure, Elective ENT elective, Caesarean section	34–66, M&F	14 g	'Unregulated wall pressure', no other settings stated	None
Parmet, 1998[43] (3)	No details	No details	14 g	340 kPa/50 psi, no other settings stated	Device failure (2) Barotrauma (2) Cardiac arrest (1)
Weymuller, 1987[26] (3)	Angioedema, ENT, Extubation failure	Incomplete details	16 g	340 kPa /50 psi, 40 jets/min	Device failure (1) Barotrauma (1)
Unpublished Anesthesia Closed Claims Project[13] (3)	No details	No details	No details	No settings stated	Device failure (3) Barotrauma (2) Difficult surgical airway (1)
Koch, 1990[40] (2)	Extubation failure	19 M, 34 F	No details	No settings stated	None
Metz, 1996[41] (2)	Cardiac surgery, Transplant surgery	1. 72 M 2. 48 M	14 g	N/A Equipment failure	Device failure (2)
Smith, 1975[23] (2)	ENT	66 M, 58 M	14 g	340 kPa /50 psi, 'intermittent' jets	Barotrauma (2) Difficult surgical airway (1) Carotid puncture (1)
Augoustides, 2007[34] (1)	Post-CEA haematoma	78 M	16 g	Anaesthesia flush valve- no other settings stated	None
Boughezala, 1997[36] (1)	Oesophageal dilation	56 M	14 g	Manual jet ventilator, no settings stated	None
Bourreli, 1984[37] (1)	ENT	62 F	14 g	410 kPa/60 psi, 12 jets/min	Barotrauma (1)
Bowdle, 1987[38] (1)	ENT	60 M	14 g	340 kPa /50 psi, no other settings stated	Tracheostomy site fire including TTJV catheter (1)
Christodoulides, 2014[17] (1)	Sepsis, hypoxia	2 M	No details	Manual jet ventilator, no settings stated	None
Divatia, 2002[39] (1)	Extubation failure	66 F	14 g	270 kPa/40 psi, 10–12 jets/min	None
McLeod, 2005[25] (1)	ENT	64 M	14 g VBM©	100 kPa/15 psi, 30 jets/min	None
Mesbah, 2013[18] (1)	Supraglottic mass	62 M	Quicktrach© II	'High flow jet ventilation', no other settings stated	Device failure (1) Barotrauma (1)
Newlands, 1996[42] (1)	ENT	42 F	14 g	340 kPa/50 psi, no other settings stated	Device failure (1) Barotrauma (1) Cervical vertebral osteomyelitis (1)

Continued

Table 1 *Continued*

Author, Yr (no. of procedures)	Clinical Circumstances	Age, Gender	Cannula size, Type	Oxygenation: Oxygen pressure kPa/psi, jets/min	Complications (#)
Prado, 2015[19] (1)	Foreign body in airway	68 M	14 g	340 kPa /50 psi, 'low frequency' jetting	None
Smith, 1974[24] (1)	Dental	6 F	16 g Teflon©	207 kPa/30 psi, 10 jets/min	None
Western Australia Coroner's Report 2001[14] (1)	Extubation failure	39 M	14g VBM©	No settings stated	Device failure (1)
Western Australia Coroner's Report 2003[15] (1)	General surgery	31 F	14 g	No settings stated	Device failure (1) Barotrauma (1) Difficult surgical airway (1)
TOTAL: 90 patients					1. Device Failure 38 (42%) 2. Barotrauma 29 (32%) 3. Misc. Complications 8 (9%) 4. Total number of procedures with any complication 46 (51%)

In the nine studies describing 42 TTJV procedures in non-CICO emergencies (Table 2), no device failures were recorded, barotrauma occurred in three (7%) and miscellaneous complications in two (5%). The total number of procedures with one or more complication was three (7%).

In the 18 studies describing TTJV in 296 elective surgical procedures (Table 3), device failure was recorded in one (0.3%), barotrauma in 23 (8%) and miscellaneous complications in three (1%). The total number of procedures with one or more complication was 24 (8%).

There was a marked heterogeneity[58] in the technique of TTJV. Where documented, there was significant variation in type and size of cannula, oxygenation source, driving pressure and jetting frequency in all three groups (Tables 1, 2 and 3). In some reports, emergency TTJV-associated subcutaneous emphysema obscured front-of-neck landmarks, hampering subsequent efforts at definitive surgical airway or tracheal intubation.[2 13 15 26] This resulted in at least one death.[13]

The proportion of complications in the three groups; emergency CICO, emergency non-CICO and elective surgery, were compared (Table 4). A higher proportion of TTJV procedures were associated with device failure ($P<0.001$), barotrauma ($P<0.001$), miscellaneous complications ($P=0.001$), and the occurrence of one or more complications ($P<0.001$) in the CICO emergency compared with the other two groups.

Discussion

Our systematic review of TTJV revealed that this technique is used in both emergency and elective surgical situations, with the former being used in both CICO and non-CICO and emergencies. We demonstrated a higher proportion of device failure and barotrauma complications in the CICO emergency situation, compared with either the non-CICO emergency or elective surgical settings.

In this review, we found a marked heterogeneity in the technique of TTJV.[58] When described, we found that the pressure settings, transtracheal catheter type and size, ventilation device and ventilation strategy differed widely. This may be related to the varied equipment recommendations found in the literature. Forty-two excluded publications recommended various combinations of equipment for emergency TTJV as 'easy'[59 60] 'simple'[61–63] or 'reliable'[64] but provided no evidence. The myriad of suggested homemade devices[65–72] may have contributed to the high rate of device failure found in our review, as equipment is perhaps used for the first time in an emergency situation. Unproved suggestions continue to be published[61] and presented.[73] In an editorial criticizing this practice, Frerk and colleagues[74] observed 'No-one would expect a pilot to learn how to make an emergency landing in a aeroplane made out of cardboard boxes in a coffee room while their colleague pretended to be air traffic control'.

There are several possible explanations for the higher rate of complications in the emergency CICO situation. The inability to facemask ventilate or perform tracheal intubation is often associated with partial or complete upper airway obstruction. In this scenario, obstruction to exhalation may lead to breath stacking and barotrauma when TTJV is used. Even if a practitioner is experienced with TTJV in the elective setting,[1 3] this skill may not be generalizable to the CICO emergency.

In the largest case series in our systematic review of TTJV use, Patel[44] described 29 consecutive emergency TTJV procedures based on CICO emergencies, in a medical intensive care unit at a Veterans Affairs Hospital in the United States. By protocol, TTJV

Table 2 TTJV use in non-CICO emergencies. ENT, otolaryngology surgery; M, male F, female; g, gauge; kPa, kilopascals; psi, pounds per square inch

Reference (no. of procedures)	Clinical Circumstances	Age, Gender	Cannula size, Type	Oxygenation: Oxygen pressure (kPa/psi), jets/min	Complications (#)
Smith 1975[23] (26)	Respiratory distress	13–65 M, details for all patients not included	14 g	340 kPa/50 psi, no other settings stated	Barotrauma (1)
Weymuller 1987[26] (7)	7 various emergencies	Incomplete details	16 g	340 kPa/50 psi, 40 jets/min	Barotrauma (1) Difficult tracheal intubation as a result of SCE (1)
Chandradeva 2005[29] (2)	Upper airway infection	54 M, 54 F	14 g VBM©	300 kPa/44 psi, no other settings stated	None
McHugh 2007[32] (2)	Cervical spine fracture, trauma	54 M, 26 M	16 g	340 kPa/50 psi, 14–16 jets/min	None
Baraka 1993[28] (1)	Angioneurotic oedema	26 M	16 g	340 kPa/50 psi, no other settings stated	None
Eyrich 1992[30] (1)	Foreign body below vocal cords	56 F	18 g followed by 14 g central venous catheter	170 kPa/25 psi, no other settings stated	None
Guo 2011[31] (1)	Foreign body	15 M	13 g Ravussin©	No settings stated	None
Love 2014[16] (1)	Respiratory distress from unknown airway mass	49 F	No details stated	No settings stated	None
Wagner 1985[33] (1)	Foreign body	65 M	14 g	340 kPa/50 psi, 60 jets/min	Barotrauma (1) Haemoptysis (1)
TOTAL: 42 procedures					1. Device Failure 0 2. Barotrauma 3 (7%) 3. Misc. Complications 2 (5%) 4. Total number of procedures with any complication 3 (7%)

Table 3 TTJV use in elective surgery. ENT, otolaryngology surgery; M, male F, female; g, gauge; kPa, kilopascals; psi, pounds per square inch

Reference (no. of procedures)	Clinical circumstances	Patient Characteristics (Age, Gender)	Cannula size, Type	Oxygenation: Oxygen pressure, jets/min	Complications (#)
Boyce 2005[48] (87)	ENT	39–80 M & F	18 g, 16.5 cm vessel dilator	170–200 kPa/25–30 psi, 10–15 jets/min	Barotrauma (2) Haematoma (1)
Layman 1983[54] (60)	ENT	5–50 M & F	14 or 16 g	No settings stated	Barotrauma (6)
Smith 1975[23] (52)	ENT	10–71 M & F	14 g	No settings stated	Barotrauma (6)
Gulleth 2005[52] (43)	ENT	37–88 M & F	13 g VBM©	No settings stated	Barotrauma (2)
Smith 1974[27] (12)	ENT	23–71 M & F	14,16,18 g	340 kPa/50 psi, no other settings stated	Barotrauma (3)
Spoerel 1971[57] (12)	Various surgeries	22–60 M & F	16 g Teflon©	340 kPa/50 psi, 12–16 jets/min	Haematoma (1)
Patel 2004[55] (10)	Maxillofacial	29–72 M & F	13 g Ravussin©	340 kPa/50 psi, no other settings stated	None
Boyce 1989[47] (8)	ENT	No details	18 g, 16.5 cm vessel dilator	15–25 jets/ min, no other settings stated	None
Weymuller 1987[26] (3)	ENT	55–65 M & F	16 g	Pressure not stated, 40 jets/min	None
Ames 1998[45] (1)	ENT	53 M	14 g Ravussin©	No settings stated	Device failure (1) Barotrauma (1)
Baraka 1986[46] (1)	ENT	17 F	18 g	410 kPa/60 psi, no other settings stated	None
Carden 1976[49] (1)	ENT	27 M	14 g	200 kPa/30 psi, TV stated as 800 cc	Barotrauma (1)
Cook 2005[50] (1)	ENT	83 M	13 g Ravussin©	No settings stated	None
Cook 2006[51] (1)	ENT	52 F	13 g Ravussin©	200 kPa/29 psi, no other settings stated	Barotrauma (1) Cardiovascular depression (1)
Layman 1983[53] (1)	ENT	14 F	14 g	340 kPa /50 psi, no other settings stated	None
McLeod 2005[25] (1)	ENT	88 M	14 g VBM©	150 kPa/22.5 psi, 30 jets/min, pause pressure 25 cmH2O	None
Smith 1973[56] (1)	ENT	66 F	16 g Teflon©	340 kPa/50 psi, 16 jets/min	None
Smith 1974[24] (1)	ENT	11 F	16 g Teflon©	270 kPa/40 psi, 10 jets/min	None
TOTAL: 296 Procedures					1. Device Failure 1 (0.3%) 2. Barotrauma 22 (8%) 3. Misc. Complications 3 (1%) 4. Total number of procedures with any complication 24 (8%)

Table 4 Comparison of complications in emergency TTJV (CICO), emergency TTJV (non-CICO) and TTJV in elective surgery. TTJV, transtracheal jet ventilation; CICO, can't intubate, can't oxygenate

	Emergency TTJV (CICO)	Emergency TTJV (non-CICO)	TTJV in elective surgery	P-value
Total number of procedures	90	42	296	
Device Failure, *n* (%)	38 (42)	0	1 (0.3)	<0.001
Barotrauma, *n* (%)	29 (32)	3 (7)	22 (8)	<0.001
Miscellaneous complications, *n* (%)	8 (9)	2 (5)	3 (1)	0.001
Procedures with any complications, *n* (%)	46 (51)	3 (7)	24 (8)	<0.001

was performed after failed tracheal intubation (two or more attempts) and the failure to maintain oxygen saturation >90% by facemask ventilation. During the 53-month (1994–1998) retrospective study period, there were 352 tracheal intubation procedures; TTJV was instituted in 8% of these because of CICO emergencies. This is a much higher rate of CICO than is usually reported in either the emergency medicine[75 76] or anaesthesia[77] literature. TTJV was instituted by house staff in five of the 29 patients, and the remainder by the attending medical intensive care physician. In the series, device failure (failure to cannulate or catheter kinking) was reported in six of 29 patients (21%) and barotrauma in four (14%).

The rate of failure of TTJV in CICO emergencies was also high in the prospective 4th National Audit Project (NAP4).[2] This audit of airway-related morbidity and mortality was conducted throughout all 309 National Health Services hospitals, over a one-year time period (2008–2009). During the audit, 19 TTJV procedures were performed via narrow-bore (usually ≤2 mm in diameter) cannulae for CICO emergencies, of which 12 (63%) failed and six resulted in barotrauma, including three occurrences of subcutaneous emphysema. Wide-bore cannulae (usually ≥4 mm in diameter, used without TTJV) failed in three of seven uses (43%). An open surgical technique performed by surgeons was almost 100% successful. This may represent a superiority of the open surgical technique over percutaneous techniques, or may also reflect the need to improve anaesthetists' training and preparedness in performing surgical airway with their chosen technique, to a level of competence closer to that of our surgical colleagues. NAP4 identified multiple mechanisms of TTJV failure, including equipment, training, insertion technique and ventilation technique. Human factors and crisis resource management may also play a role.[78] Of note, a number of recent studies have found that anaesthetists fail to accurately identify the cricothyroid membrane by external palpation in a high percentage of patients,[79–81] consistent with the proportion of failed cannula cricothyroidotomy attempts in NAP4.

The Anaesthesia Closed Claims Project[82] contributed 12 TTJV procedures in CICO emergencies to our review. Nine procedures, occurring between the years 1985–1999, were published by Peterson.[11] Three additional procedures were identified between 2000 and 2012 by data request to the Anaesthesia Closed Claims Project administrator.[13] All Anaesthesia Closed Claims Project patients are based on closed legal proceedings and are thus retrospective in nature. In addition, given that the Anaesthesia Closed Claims Project is based on anesthetists involved in malpractice proceedings, the findings may be biased towards negative outcomes of a particular clinical situation and/or procedure.

TTJV has been recommended as a temporizing strategy before open or surgical front-of-neck access.[8] However, one unexpected finding of the present review related to reports of TTJV-associated subcutaneous emphysema[2 13 15 26] obscuring airway landmarks, causing subsequent difficulty with definitive surgical airway access or tracheal intubation. Thus, in addition to its high risk of failure, TTJV may impede further efforts to secure a definitive airway.

There are several limitations to our systematic review that deserve consideration. CICO is reported to occur in approximately 1:12 500 general anaesthetics,[77] and 3–8:1,000 tracheal intubation attempts in the emergency department setting.[75 76] Thus, we expected to find more emergency TTJV procedures in the literature. For example, the Difficult Airway Society paediatric CICO guidelines[4] include TTJV as an option in children one to eight yr of age, yet our review identified only two procedures in this age group during a CICO emergency.[17 27] Reporting and publication bias against publishing complications, or poor outcomes,[58] may have contributed to the relative paucity of emergency TTJV procedures identified in our systematic review. Alternately, it may be that TTJV is simply not commonly used in the CICO scenario, despite its inclusion in several guidelines.[7–10]

TTJV has been recommended for more than twenty years as a potentially life-saving procedure in a CICO emergency.[5–8] In the NAP4 study, it was found that 'anaesthetists almost exclusively chose cannula techniques' when faced with a CICO scenario.[2] TTJV remained the second choice after a wide-bore wire-guided cannula technique in a recent CICO survey study of Canadian anaesthetists.[83] In contrast, the 2015 Difficult Airway Society guidelines recommend an open surgical technique over either narrow or wide-bore cannula techniques, based on an increased probability of success.[1] Our study lends support to this recommendation, given the high rate of complications associated with TTJV in the CICO emergency.

Authors' contributions

Study design/planning: L.V.D., B.B.S., J.A.L., I.R.M., M.F.M., D.E.G.
Study conduct: L.V.D., B.B.S., J.A.L., I.R.M., M.F.M., D.E.G.
Data analysis: L.V.D., B.B.S., J.A.L., I.R.M., M.F.M., D.E.G.
Writing paper: L.V.D., B.B.S., J.A.L., I.R.M., M.F.M., D.E.G.
Revising paper: all authors

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Declaration of interest

None declared.

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Appendix 1: Search strategies

Ovid MEDLINE(R) In-Process & Other Non-Indexed Citations and Ovid MEDLINE(R) 1946 to Present

1. exp Airway Management/
2. airway management.ti,ab
3. oxygenat*.ti,ab
4. ventilat*.ti,ab
5. Or/1–4
6. transtracheal.ti,ab
7. trans-tracheal.ti,ab
8. cricothyrotomy.ti,ab
9. cricothyroidotomy.ti,ab
10. Or/6–9
11. And/5,10
12. Limit 11 to (english or French)

Embase 1974 to 2016 March 29

1. exp respiration control/
2. airway management.ti,ab
3. oxygenat*.ti,ab
4. ventilat*.ti,ab
5. Or/1–4
6. transtracheal.ti,ab
7. trans-tracheal.ti,ab
8. cricothyrotomy.ti,ab
9. cricothyroidotomy.ti,ab
10. Or/6–9
11. And/5,10
12. Limit 11 to (english language or french)

Cochrane Database of Systematic Reviews 2005 to March 23 2016
ACP Journal Club 1991 to March 2016
Database of Abstracts of Reviews of Effects 1st Quarter 2016
Cochrane Central Register of Controlled Trials February 2016
Cochrane Methodology Register 3rd Quarter 2012

Health Technology Assessment 1st Quarter 2016
NHS Economic Evaluation Database 1st Quarter 2016

1. transtracheal.ti,ab
2. trans-tracheal.ti,ab
3. cricothyrotomy.ti,ab
4. cricothyroidotomy.ti,ab
5. Or/1–4
6. limit 5 to (english or french) [Limit not valid in CDSR,ACP Journal Club,DARE,CLCMR,CLEED; records were retained]

Unpublished Literature
transtracheal OR trans-tracheal OR cricothyrotomy OR cricothyroidotomy

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SPECIAL ISSUE

The Vortex: a universal 'high-acuity implementation tool' for emergency airway management

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Abstract

Factors influencing performance during emergency airway management can be broadly divided into issues with preparation and those with implementation. Effective design of resources that provide guidance on management requires consideration of the context in which they are to be used. Many of the major airway guidelines do not specify whether they are intended to be used during preparation or implementation and may not take the context for use into account in their design. This can produce tools which may be not only ineffective but actively disruptive to team function in an emergency. The Vortex is a novel, simple, and predominantly visually based cognitive aid, which has been specifically designed to be used in real time during airway emergencies to support team function and target recognized failings in airway crisis management. Unlike the major algorithms, which are context specific, the Vortex is flexible enough for the same tool to be applied to any circumstance in which airway management takes place, independent of context, patient type, or the intended airway device. This makes the same tool suitable for use by emergency physicians, intensivists, paramedical staff, and anaesthetists. The Vortex contains many of the recognized features of an ideal cognitive tool and may be effective in reducing implementation errors in emergency airway management. Experimental evidence is required to establish this.

Key words: airway management; crew resource management, healthcare; emergencies; emergency treatment; human engineering; medical errors; patient safety

Factors influencing performance during emergency airway management can be broadly divided into those relating to preparation and those relating to implementation (Fig. 1). Clinician preparation includes all aspects of training, experience, consultation, and planning. Even appropriately prepared clinicians, however, can make basic errors during emergency airway management.[1–3] Rather than reflecting a lack of skill or knowledge required to manage a situation, these errors often involve clinicians becoming cognitively overloaded in situations of stress.[1–8] This compromises their ability both to evaluate the situation and to recall available rescue strategies. Impaired decision-making, fixation, omission, or failure to act are recognized consequences.[1–6 9] Such errors are often compounded by an inability of clinical teams to function effectively.[1 3 4] Psychological barriers to abandoning the various upper airway techniques in favour of invasive techniques, such as emergency cricothyroidotomy, may further reduce performance.[10 11] Rather than necessarily involving failure to prepare, these issues represent a problem with implementation of the airway plan, although preparation and implementation issues may often coexist within the same clinical situation.[10]

Tools providing guidance on appropriate management can be used during either the preparatory or implementation phases to assist with performance of a task.[4] The taxonomy outlined in Fig. 2 has been coined for this article to improve clarity when discussing these tools. Guidelines, protocols, and procedures can be considered 'foundation tools', which help to explain the task (and the underlying theory) before the event to promote understanding or memory. In contrast, the term 'cognitive aid' specifically refers to 'implementation tools', intended to prompt the user during performance of the task.[2 4 6 7]

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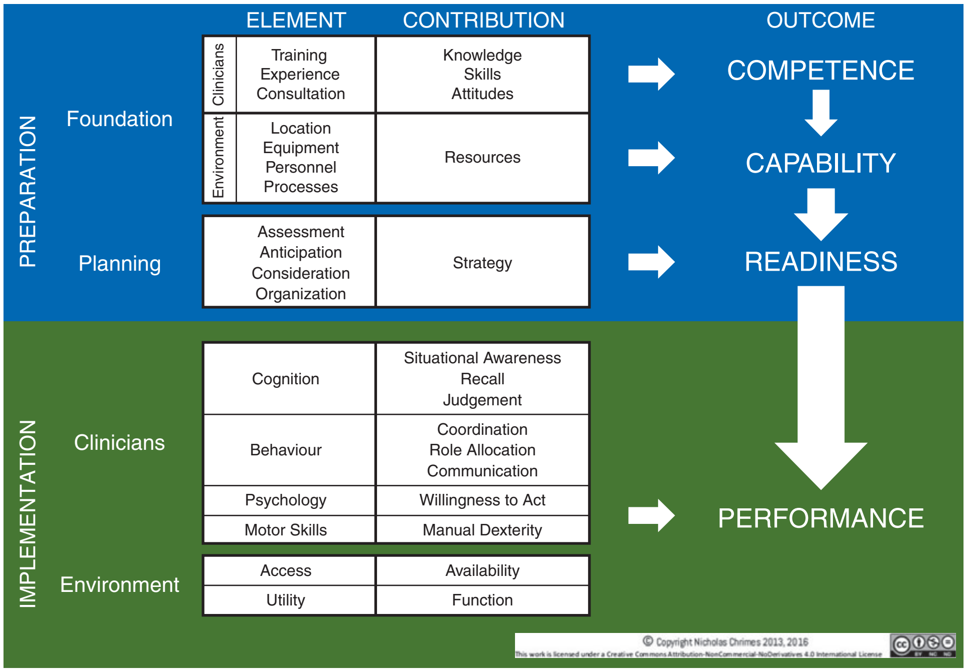

Fig 1 Factors contributing to clinical performance.

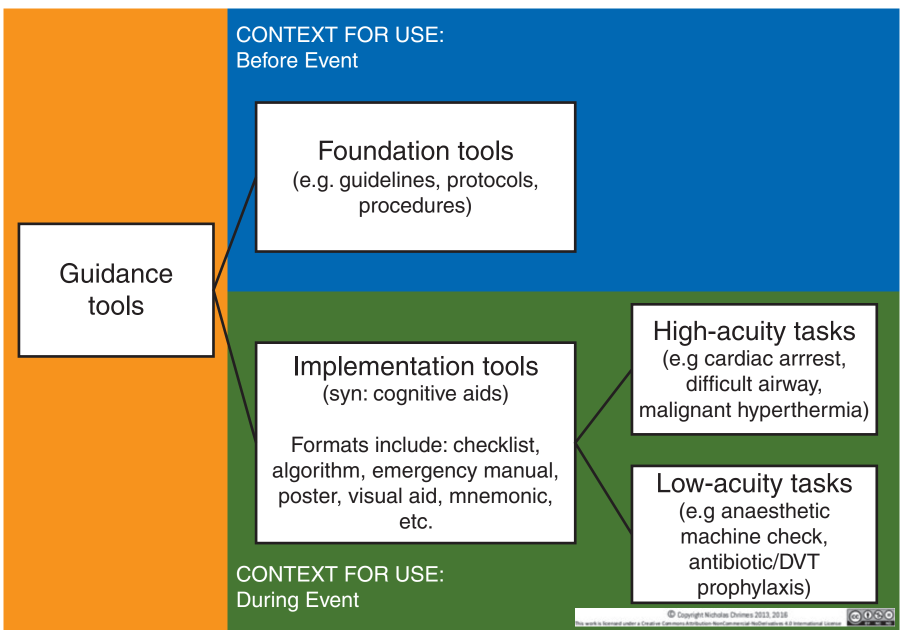

Fig 2 Classification of guidance tools. DVT, deep vein thrombosis.

The effectiveness of guidance tools is dependent upon both their technical content and how that content is presented. The design requirements of guidance tools differ significantly depending on the context in which they are to be used.[4 6 7] Well-constructed implementation tools have the potential to facilitate team situational awareness, improve communication, prompt decision-making, and guide key actions.[2 6 12 13] If poorly designed, however, implementation tools also have the potential to impair performance and cause harm.[6] Foundation tools will typically be too detailed or complex to refer to during performance of a task.[4 6] Likewise, implementation tools intended for low-acuity tasks will have different design requirements from those intended for use during high-acuity tasks.[2 4 6] Despite this, not all difficult airway guidance tools specify whether they are intended to be used to lay a foundation or referred to during implementation.[4] In anaesthesia, even tools intended for use during implementation are largely developed with content as the major focus, without necessarily addressing the human factors considerations needed to enhance their utility in a particular context.[6]

The 2015 Difficult Airway Society (DAS) guidelines explicitly state that they are intended for use as a foundation tool, while acknowledging the Vortex as having a purpose distinct from their own.[5] The Vortex is a 'high-acuity implementation tool' designed to support teamwork and decision-making during the high-stakes, time-critical process of managing an airway emergency.[14 15]

Development

Using grounded learning theory, based on more than 15 years of clinical experience in anaesthesia and exposure to hundreds of simulated crisis events as a simulation instructor, the author created the Vortex to address a perceived deficit in the existing guidance tools for emergency airway management. The concept was to provide a single, consistent implementation tool that could be used during an airway crisis by inter-professional teams across all specialties involved in advanced airway management. Designing an implementation tool for this purpose demands that it is presented in a way that enables it to be used in real time by teams of potentially highly stressed individuals. It also requires that the same tool is flexible enough to be capable of being applied to all circumstances in which advanced airway management takes place, independent of the context, the patient type, or the primary intended airway device.

The information-dense, text-based presentation of the major airway algorithms,[5 16–19] despite being technically accurate, makes it more difficult for teams to use the information within them during the stress and uncertainty of an evolving airway emergency.[2 4] The major airway algorithms also tend to provide context-specific guidance. Separate algorithms have been developed to apply to adult,[5 17] paediatric,[18] and obstetric[17 19] patients. Complicating matters further is that most of these algorithms exclusively address the circumstance in which the primary intended airway is an endotracheal tube[5 16 17] but not the common situation in which the primary intended airway device is a supraglottic airway or even face mask ventilation.[1] The resultant multiplicity of algorithms and their inability to be applied directly to a large proportion of situations in which airway crises arise may increase the cognitive load associated with their use. This has the potential further to reduce their utility as implementation tools during an airway crisis.[20]

A simple, low-content, predominantly graphic design is recognized to make a guidance tool more suited to real-time use during crisis situations.[4] To maintain such a design, the Vortex makes two assumptions. The first is that the tool will be used by clinicians who are already competent to perform advanced airway management independently. As such, its role is to prompt implementation of previously learned knowledge and skills. The Vortex is not intended to teach clinicians or compensate for deficiencies in training, experience, consultation, or planning. The expectation is that the tool should prompt a clinical team with the options for airway management and facilitate shared situational awareness. Given these prompts, preparatory activities should have provided clinicians with the basis to make a judgement on the best course of action to take in a given context and the technical skills for implementing it. The second assumption the Vortex makes is that teams have been trained in its use before the occurrence of an airway crisis. Familiarity is recognized as being important for a crisis management implementation tool to be effective[6 7] and removes the need for it to include complex explanatory detail.

The context-independent nature of the Vortex also allows the same tool to be used in any clinical situation in which an airway crisis might arise. Avoiding the need to choose between multiple algorithms may improve familiarity and recall under stress, further enhancing utility as an implementation tool.

The prompts provided by the Vortex address factors recognized to impair implementation of airway management, including the following: failure to consider all available techniques for achieving airway patency; failure to consider all the strategies available for optimizing success at each of these; excessive airway instrumentation; failure to recognize the significance of achieving alveolar oxygen delivery; failure to recognize the 'can't intubate, can't oxygenate' (CICO) situation; lack of priming for emergency front-of-neck access; delayed implementation of emergency front-of-neck access; and impaired teamwork.[1 3 4 10 11]

Description

Overview

The Vortex is based on the principle that there are three 'non-surgical' techniques to establish a patent airway: use of a face mask, a supraglottic airway, or an endotracheal tube. If a best effort at each of these three upper airway 'lifelines' is unsuccessful, then airway patency must be restored by initiating 'CICO rescue' (emergency front-of-neck access). Rather than the traditional algorithm-based design, the Vortex uses a simple graphic that depicts the upper airway lifelines as three zones arranged in a circular fashion around a central area representing CICO rescue (Fig. 3). If a 'best effort' at any of the three lifelines is unsuccessful, this mandates spiral movement inward to the next lifeline. The circular arrangement of the three lifelines means that airway management can commence with any lifeline and proceed between the remaining ones in any sequence according to what is judged most appropriate in a given context. This more accurately depicts real-world practice than the rigid sequence mandated by an algorithm.[4] Inability to establish alveolar oxygen delivery after best efforts at all three lifelines culminates in arrival at the central zone, representing the need to initiate CICO rescue.

Best efforts

According to the Vortex model, achieving a best effort at any upper airway lifeline may involve up to three attempts (although the minimal possible number should be used). Not all attempts in pursuit of a best effort at a particular lifeline have to be completed before initiation of the first attempt to establish an alternative lifeline. Consistent with clinical practice, best efforts at multiple lifelines may progress in parallel, with sequential attempts alternating between optimizing different lifelines.[4] Movement around the Vortex thus tracks the sequence in which best efforts at each lifeline are completed, rather than the sequence in which individual attempts to achieve this are undertaken.

Any repeated attempt at a lifeline must incorporate optimizations that have not previously been implemented. Five categories of optimization are presented on the tool to prompt consideration of the available options for maximizing the likelihood of

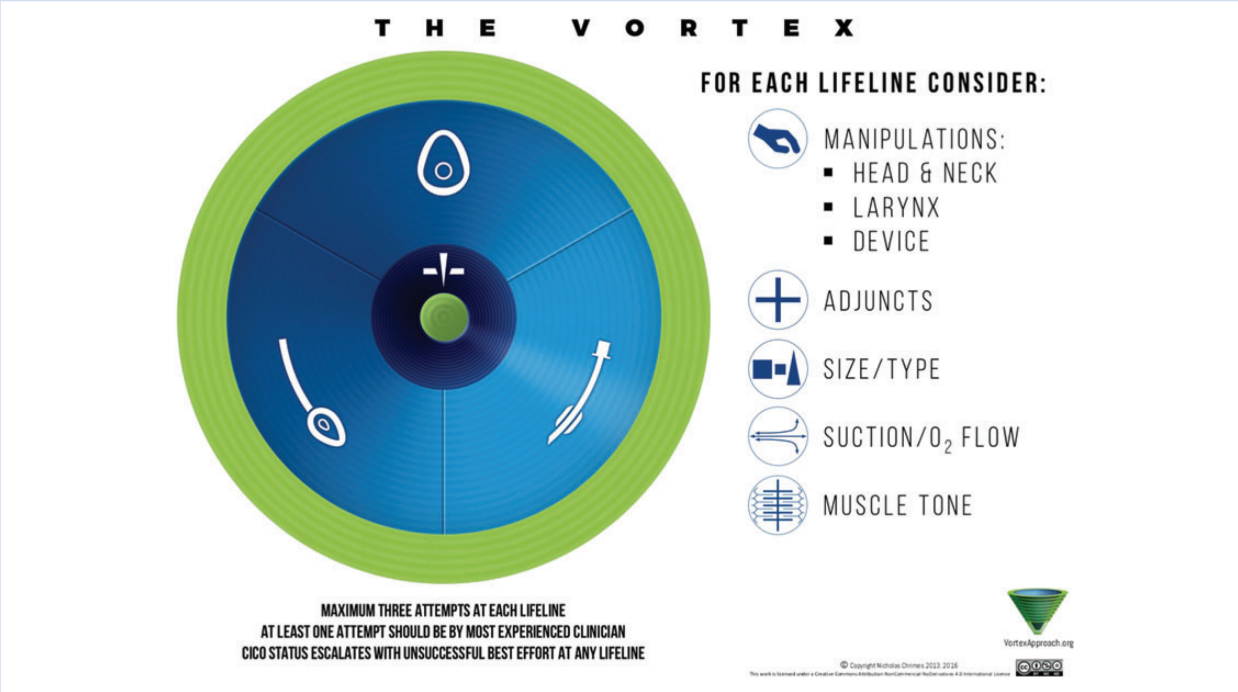

Fig 3 The Vortex implementation tool.

achieving airway patency with any of the three lifelines. The specific interventions relevant to each individual lifeline under these headings are taught to clinicians as part of training with the implementation tool. Exhaustive implementation of all these interventions would be both time consuming and inappropriate. What constitutes a best effort and a reasonable number of attempts to achieve it is a context-dependent decision. The category headings serve only to prompt consideration of the available options. This is important from two perspectives: firstly, it facilitates efficient achievement of a best effort, maximizing the chance of timely success with each lifeline; and secondly, it provides a defined end point to optimization and promotes team recognition of the need to move on to a different technique when a best effort has been unsuccessful. Ultimately, if all three lifelines are unsuccessful, it provides the team with permission to initiate CICO rescue.

The green zone

Inability to achieve alveolar oxygen delivery after a best effort at any lifeline mandates spiral movement towards the centre of the Vortex. In contrast, confirmation that adequate alveolar oxygen delivery is being achieved (typically by obtaining an end-tidal carbon dioxide trace in combination with maintenance of adequate oxygen saturation) results in movement outwards into the circumferential 'green zone' at the perimeter of the tool. The green zone is also visible in the centre of the tool, representing the ability of CICO rescue to restore alveolar oxygen delivery when all upper airway lifelines have been unsuccessful.

Entry into the green zone, via any technique, signifies a crucial point in airway management, during which the patient is no longer at imminent risk of critical desaturation. Acknowledging this situation of relative safety can potentially arrest the momentum of repeated airway instrumentation that might convert the 'can oxygenate' situation into the 'can't oxygenate' situation. Declaration of being in the green zone by any member of the team provides a cue to consider the opportunities this provides: the opportunity to restore patient oxygen saturations and alveolar oxygen stores, the opportunity to assemble resources (equipment, personnel, and location), and the opportunity to make a plan. Planning options are divided into the following three broad categories: the first is to maintain the lifeline by which the green zone has been achieved (and either proceed or 'wake' the patient); the second is to convert the lifeline to a preferred technique to maintain airway patency without intending to leave the green zone (e.g. use of an Aintree catheter or performance of a surgical airway); and the third is to replace the current upper airway lifeline with a different one (e.g. interrupt face mask ventilation to re-attempt intubation). This last option involves deliberately leaving the green zone and relinquishing the technique by which alveolar oxygen delivery is being achieved. The appropriateness of each of these options varies according to the context. Considerations to assist in this decision are highlighted as part of training and prompted in the moment using a separate implementation tool (Fig. 4). Whichever option is selected in the green zone, planning should always include preparation for the contingency that airway patency is lost. This should include a strategy to complete best efforts at any remaining upper airway lifelines and an appropriate level of priming to perform CICO rescue.

Can't intubate, can't oxygenate status

Declaration that a best effort at any lifeline has been unsuccessful mandates an escalation in the 'CICO status'. This specifies predefined actions for obtaining help and priming the team to perform CICO rescue, according to a three-tiered ready–set–go set of criteria outlined on a separate adjunctive implementation

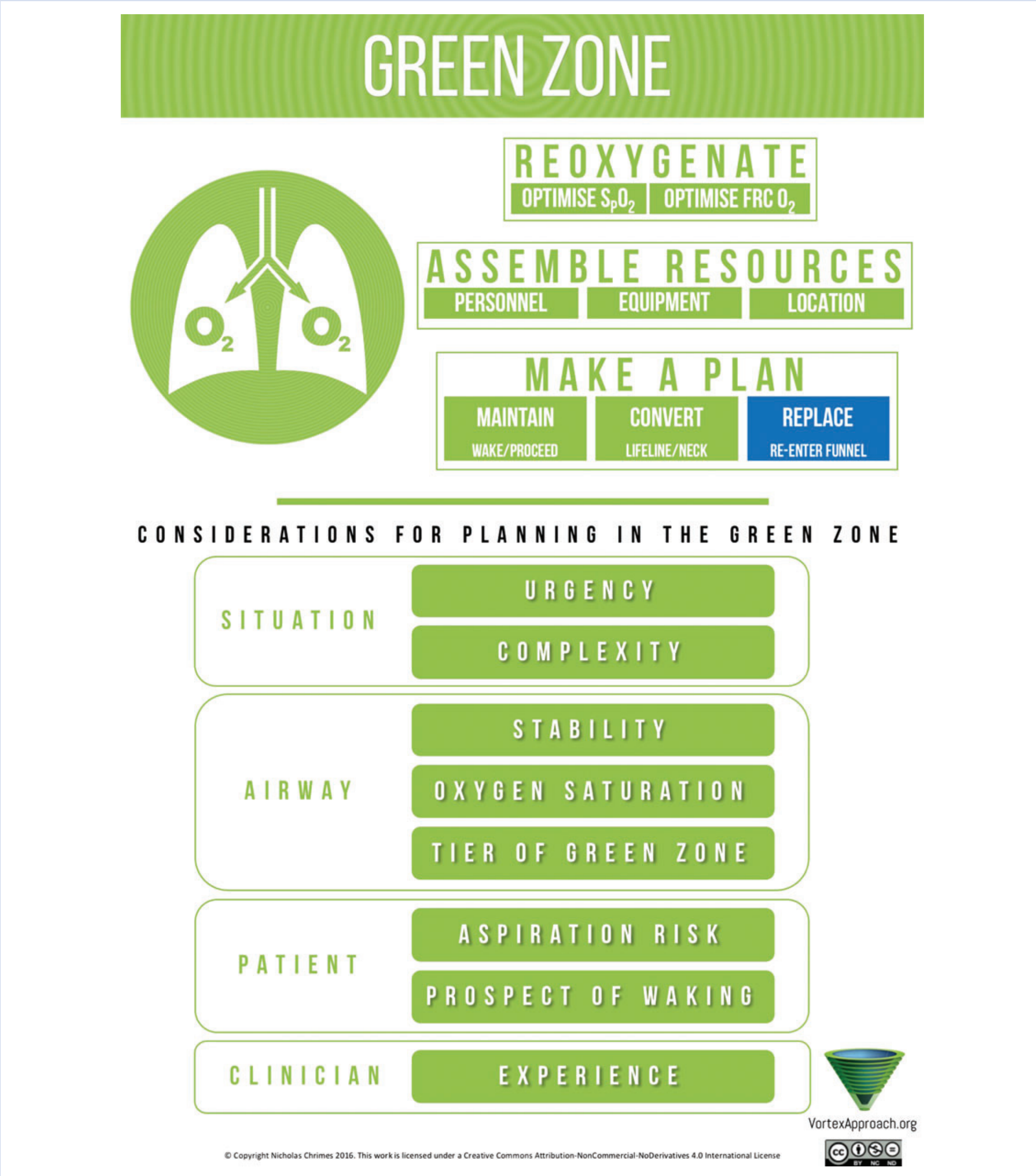

Fig 4 Adjunctive implementation tool.

tool (Fig. 5). The CICO status thus serves to facilitate early transition to CICO rescue by integrating both practical and psychological priming for this confronting procedure in parallel with successive unsuccessful attempts to establish airway patency via the upper airway lifelines. Team leaders may also trigger an additional escalation in CICO status according to other recommended criteria or their own clinical judgement, but CICO status should not reach 'go' until a declaration is made that best efforts at all three lifelines have been unsuccessful.

Conceptual imprinting

The circular graphic on the Vortex implementation tool is intended to represent looking down into a funnel. Narrowing of

Fig 5 The ‘can’t intubate can’t oxygenate’ (CICO) status implementation tool.

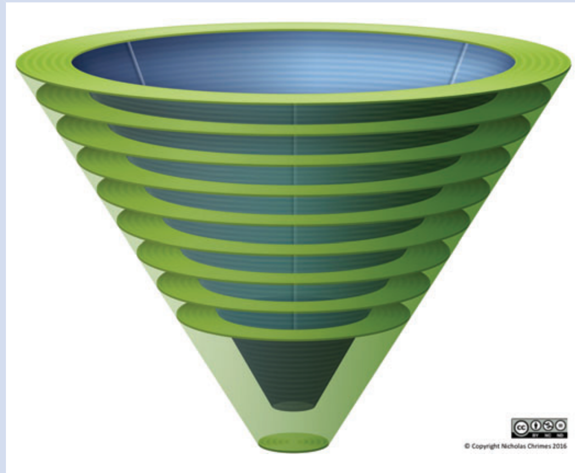

Fig 6 Lateral aspect of Vortex in three dimensions, demonstrating funnel concept.

the funnel implies the diminishing time and options available as one spirals deeper into the Vortex and the inevitability of needing to initiate CICO rescue once best efforts at all three lifelines have been unsuccessful. The deepening blue colour lower in the funnel suggests imminent hypoxaemia if airway patency is not restored. These visual cues are intended to promote team situational awareness. The pattern of concentric rings in the circular CICO rescue zone at the bottom of this funnel deliberately evokes the visual perspective of looking down the lumen of the trachea, with the ‘shard’ icon penetrating its wall. This creates an additional graphic prompt for initiating CICO rescue. The juxtaposition of the central green zone with the bottom of the funnel is intended to balance the inherent conflict associated with performance of CICO rescue: it is undesirable if avoidable but essential when indicated. Although it is important to reinforce that CICO rescue is an invasive procedure to be used as a last resort in airway management, in isolation this concept and the bottom-of-the-funnel metaphor could be interpreted as intimidating and implying failure of the clinician. This potentially creates a psychological impediment to proceeding to CICO rescue that might delay or deter performance of this procedure when it is required. If best efforts at all lifelines have been unsuccessful, CICO rescue is a crucial intervention to make the patient safe. The visibility of the green zone at the bottom of the funnel is intended to convey this path to safety and to encourage clinicians to proceed in this circumstance.

A supplementary illustration used for training (a ‘foundation graphic’ which is not part of the implementation tool) shows the lateral aspect of the Vortex in three dimensions to demonstrate the funnel concept (Fig. 6). In this three-dimensional image, the area where alveolar oxygen delivery cannot be confirmed is represented by the interior of the funnel. The sloping surface inside the funnel reinforces the need to implement best efforts efficiently to restore airway patency via each of the upper airway lifelines in order to avoid clinical deterioration. In contrast, the green zone encompassing the funnel (enabling it to be visible both inside and outside the funnel on the implementation tool) comprises horizontal surfaces, emphasizing that it represents an opportunity to pause and plan.

Using the visual metaphor of a funnel provides a ‘conceptual imprint’ to convey these additional aspects, obviating the need for the implementation tool itself to make explicit reference to them and allowing it to maintain a simple, low-content interface. The conceptual imprinting process is supplemented by the vivid nature of the name ‘Vortex’, which affords a concise mechanism for some of these imprinted concepts to be expressed further verbally, as in the example below. Moreover, the Vortex moniker and its associated logo create a ‘brand’, exploiting strategies used in marketing to heighten memorability. This has the potential to enhance awareness and recall of the implementation tool and its underlying concepts which augments the utility of the tool, during the stress of managing a challenging airway.

Critical language

The emphasis of the Vortex is on team performance rather than performance of the individual clinician. The Vortex creates a common template for airway management that is intended to facilitate team situational awareness. Cardiac arrest management includes verbal declarations, such as ‘no pulse’ or ‘shockable rhythm’, which convey critical moments of situational awareness to the clinical team. These create a shared mental model and assist team members in anticipating the next steps in management. Such critical language is known to be important to enhancing teamwork and minimizing error, particularly between clinicians from different clinical backgrounds.[8] In addition to the graphic tool, the Vortex introduces standardized terminology, such as ‘completed best effort’, ‘in the green zone’, ‘CICO status’, and ‘sucked into the Vortex’. This provides an analogous lexicon to facilitate airway crisis management.

Discussion

The design requirements of a guidance tool for airway emergencies differ according to whether the intention is for it to be used before or during the occurrence of an airway crisis. An effective high-acuity implementation tool must address not only the specific technical factors known to impair clinical performance but also the human factors that make it able to be used in situations of stress.[6 7] The Vortex implementation tool has been developed with consideration of these principles to create a novel, simple, visually based tool, which is better suited for real-time use in an emergency than the traditional high-content, text-based decision algorithms.[4] The Vortex should not be considered an alternative to these algorithms but a complementary tool, intended to facilitate implementation of the principles they advocate, and assist clinical teams to perform under pressure.

The primary purpose of the Vortex is to avoid the CICO situation by facilitating efficient implementation of best efforts at each of the upper airway lifelines and encouraging recognition of the significance of achieving alveolar oxygen delivery, even when this has not been achieved by the primary desired method. It also prompts early priming for CICO rescue as an airway scenario evolves and gives teams permission to implement this in the rare situation where all three upper airway lifelines are unsuccessful and CICO is declared.

Another distinguishing feature of the Vortex is that it has been designed to be flexible enough to be applied universally to all episodes of airway management. This single tool can be used by all clinical teams who deal with airways, not only in anaesthesia but also in emergency medicine, intensive care, prehospital, and other resuscitation settings. By providing a common template across specialties, the Vortex may be particularly beneficial in enhancing teamwork and communication when these diverse groups of clinicians come together at short notice to manage airway emergencies.

Although designed to be referred to during an unfolding airway crisis, previous familiarity and training in use of the Vortex tool is required for it to be used effectively. The Vortex implementation tool is only one aspect of the broader 'Vortex Approach', which provides complementary foundation material using the same language and concepts, supported by an inter-professional team training programme.[14 15] Even the implementation tool itself is not restricted to being used during an unfolding emergency. It can also be used in a lower acuity setting as a format for clinicians to plan airway management for a particular patient, enabling them to make decisions and brief the team in advance. This might include anticipating the sequence in which upper airway lifelines will be attempted, the optimizations to maximize their potential for success, and the definitive end points of a completed best effort. This provides teams with the opportunity to clarify strategy and ensure availability of resources before embarking on airway management. In addition, use of the implementation tool as a template for planning routine management would be expected to enhance familiarity and reinforce the Vortex model, with potential improvement in the ability to recall and use the tool in an emergency setting. Given the simplicity of the implementation tool and the conceptual imprinting provided by the visual metaphor of the funnel, it is conceivable that sufficient familiarity could ultimately lead to the physical representation of the Vortex becoming irrelevant in the emergency setting. Instead, the tool could be seen in the mind's eye of clinicians, which is recognized to be an ideal feature of an implementation tool.[20]

The Vortex exhibits many features of an ideal implementation tool.[6 20] A recent report on transition to CICO rescue identifies the potential of the Vortex directly to target human factors affecting team performance and protect against fixation and omission errors in an airway crisis.[4] Anecdotal use of the Vortex during real airway emergencies supports this idea,[21] but experimental research is now needed to establish its validity.

Declaration of interest

All intellectual property relating to the Vortex is owned by the author and is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License.

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Is it time for airway management education to be mandatory?

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Complications secondary to airway management in anaesthesia are relatively rare but when they do occur, the causal and contributory factors are often attributed to human error related to inadequate training and poor judgement by the anaesthetist.[1] These complications continue to occur despite competency-based medical education curricula and detailed practice guidelines.

One criticism of competency-based medical education is that it applies primarily to trainees and focuses too much on the development of competencies which some regard as a minimum standard of ability.[2] Senior anaesthetists are expected to be experts in airway management, but to maintain that standard, specialists need a comprehensive education program in airway management that goes far beyond the standard expected of a trainee.

Anaesthetists are subjected to a constant stream of new techniques and devices for airway management.[3] New equipment is introduced with little formal instruction, resulting in a tendency to use it without checking or reading the instructions.[4] This can result in the type of morbidity and mortality that has been documented with videolaryngoscopes and airway exchange catheters.[5 6] After one particularly tragic patient, a regional Medical Director wrote,

> Following an inquiry into the death of a patient in one of our hospitals, the inquiry team has asked me to write to all medical staff to remind you that you should ensure that you are trained in the use of all equipment you may be required to use.
>
> While this may seem self-evident, there is an occasional requirement to use equipment, especially in the emergency setting, which you may use at no other time. It is essential that you are familiar with such equipment and its proper use.[7]

Years of experience do not always translate into expertise, especially with new and rarely used techniques. Experience may decrease the *effort* of performance by producing automaticity, but this does not necessarily improve the *quality* of performance. On the contrary, skills can deteriorate with advancing yr. For example, the decline in psychomotor skills after 45 yr of age has been shown to impact on the ability to perform a cricothyroidotomy.[8] Furthermore, senior practitioners show poor self-awareness of declining ability and tend to overrate their ability with advancing age.[9] To develop and maintain expertise throughout one's professional life, a practitioner needs to take on new challenges regularly. Deliberate practice, immediate feedback, problem solving and evaluation, with opportunities to repeat performance and optimize behavior, are the essential ingredients of building expertise.[10]

There are many opportunities for anaesthetists to engage in airway management education. The apprenticeship model of medical education is still regarded as the standard for medical teaching. Learning airway management from an experienced clinical teacher during patient care has the advantage of involving real anatomy, physiology and pathology with a wide range of patient presentations. This type of experience can be invaluable if the circumstances provide appropriate conditions for teaching. Procedural skill can develop in the operating room relying on the accumulation of experience from patient contact. Alternatively, learning may be guided by colleagues, or attending training courses and conferences. There are regular, formal airway courses promoted by national bodies such as the Difficult Airway Society, the Royal College of Anaesthetists and Association of Anaesthetists of Great Britain and Ireland. Other sources of information include e-learning, social media, didactic instruction at conferences, simulation based medical education (SBME) and self-directed learning.[11]

There are many weaknesses in the traditional model of learning experientially in the operating room. In situ clinical education is constrained by the serendipitous nature of difficult airways and the lack of immediately available expert instruction. Teaching in the operating room not only uses valuable operating room time, but it can distract from patient care. Therefore, experiential learning is the least compatible with our goal for improved patient safety. Additionally, performance in the operating room is rarely evaluated for potential optimizations. For these reasons, opportunities to learn and assess procedural skill outside the operating room are worth exploring.

Simulation based medical education

Simulation based medical education has the potential to supplement and, in many cases, supplant operating room education.[12] During simulation based education, practitioners are afforded the opportunity to learn at their own pace, without the attendant risks of causing patient harm. Through simulation, varying degrees of difficulty can be created and then introduced to the learner in a deliberate and intentional order, so as to deepen and solidify their knowledge. Rare events can also be introduced and then drilled to broaden learning opportunities that are infrequent in the operating room. Clinical skills can be broken down, allowing for the individual biomechanical techniques to be optimized and the cognitive responses to be fine-tuned, until the entire performance is perfected. Additionally, simulation facilitates assessment, performances can be observed, and feedback given without interrupting procedures.

Practice guidelines

Efforts to improve airway management through practice guidelines can best be achieved if educational programs reflect the recommendations of those guidelines. The Difficult Airway Society (DAS) 2015 guideline mentions a number of airway procedures: the authors acknowledge that regular practice, training and skill are required to use a videolaryngoscope, perform scalpel cricothyroidotomy and show competence with second generation supraglottic airway devices. Other techniques in the guideline include awake intubation and intubation via a supraglottic airway device: techniques which may require skill with a flexible bronchoscope. Optimal use of a stylet, gum elastic bougie and Aintree catheter are also highlighted as necessitating training and practice. The DAS guideline for the management of tracheal extubation discusses the use of the advanced techniques of laryngeal mask exchange (Bailey manoeuvre) and the remifentanil technique.[13] It is recommended that all anaesthetists should be familiar with the use of airway exchange catheters, devices which are notorious for barotrauma and death when used incorrectly or in conjunction with transtracheal jet ventilation.[6] Additionally, ultrasound examination of the airway is another relatively new skill recommended for anaesthetists to master. All of these procedures could, therefore, form the nidus for a comprehensive airway management training program.

Mandatory education

It is tempting to suggest that by introducing mandatory education in airway management, the problems associated with poor judgement and inadequate training will decrease. Mandatory airway education has already been established in many jurisdictions, where attendance at courses and other forms of education are required for continuing certification. Unfortunately such mandates invariably relate to attendance rather than to a required level of performance that proves competence. Ideally, mandatory airway education would be accompanied by performance assessment and then followed by audits to demonstrate improvements in patient care.

Creating a mandate for specialist education in airway management would necessitate selecting which aspects to include. The NAP4 study showed that difficult or delayed intubation, failed intubation and cannot intubate, cannot oxygenate (CICO) situations accounted for 39% of events during anaesthesia and CICO accounts for 25% of all anaesthesia related deaths. It is, therefore, quite reasonable to expect that every airway practitioner should be able to perform an emergency front of neck access procedure. This concept is promoted in the Difficult Airway Society 2015 guidelines which state that scalpel cricothyroidotomy should be practised by all anaesthetists.[14]

The Australian and New Zealand College of Anaesthetists (ANZCA) has a continuing professional development (CPD) programme that requires participants to complete two of four emergency response activities (CICO, cardiac arrest, anaphylaxis, and major haemorrhage) each CPD triennium. It is at the discretion of participants to choose which emergency response activity to complete relevant to their scope of practice. Many practitioners are completing a CICO module each triennium, but it is not mandatory to do so.

Problems with mandatory CICO training

A potential problem with mandatory airway education is that, unless the program is comprehensive, practitioners may focus on those aspects of training which are compulsory, such as the CICO module, rather than many other crucial aspects of their airway education. Thus, the irony of emphasizing the management of CICO is that this may generate neglect of the techniques required for the avoidance of CICO.

Root cause analysis of airway deaths invariably reveals a cascade of system failures. A CICO event is usually the result of an unpredictable combination of human and organizational failures at multiple levels: a scenario clearly explained by Reason's Swiss cheese model.[15] In the Swiss cheese model, defences, barriers and safeguards are placed between hazards existing before the barriers and the inflicted losses which arise when the barriers fail. Although it occurs rarely, these defenses can fail in unison. Such a failure in airway management can result in a catastrophic inability to oxygenate the patient. Learning the CICO module, in isolation, is akin to teaching pilots how to crash land an aeroplane without emphasizing the skills required to fly safely, particularly under adverse conditions. A mandatory comprehensive airway management program would address the behaviours, knowledge and skills which are essential for an expert airway practitioner to safely plan and conduct airway management. Therefore, careful attention must be paid to crafting a balanced approach to mandatory airway education.

Mass education of cricothyroidotomy raises a number of issues. Predictably, programs proliferate, leading to variable standards and quality.[16] How will the teachers be trained and what standards will apply to the instructors? Teaching airway management depends on the knowledge and teaching ability of the teachers. Instructors need to be trained to comply with curriculum criteria and fully understand their subject. Train-the-trainer courses are available, which aim to improve teaching skills and knowledge, but rarely include follow-up assessment of the instructors.

Hands-on teaching is demanding of teachers' time and equipment, but alternative techniques are being explored in the United States Veterans Health Administration (VHA).[17] The VHA system covers 136 hospitals caring for nine million patients and is currently producing for trial a mandatory, performance-based Difficult Airway Algorithm and Rescue Cricothyrotomy (DAARC) program for all airway managers. DAARC is a novel composite program comprised of a didactic video, video-directed task training, and an avatar based game with formative and summative portions. DAARC focuses on the use of the Vortex approach airway cognitive aid and incorporates the open cricothyroidotomy technique.[18] The learners' completion of DAARC will be based on validated in-game assessments of airway approach, appropriateness of optimizations and time taken to secure an airway. The application of an e-learning and gaming approach in DAARC potentially reduces the financial burden of mandatory training, while maintaining consistent cognitive training, in an extensive healthcare system.

How often should this training occur? The interval between repeated training is determined by the skill decay rate. Simulation training for cricothyroidotomy has been associated with skill retention, technical ability and compliance with an algorithm for up to one year.[19] What form of valid and reliable assessment should apply to cricothyroidotomy training? Check lists and global rating scales, in conjunction with direct observation, are known to be reliable assessment tools for procedural skill in this context.[8] It has yet to be shown that mass education on this scale will have the desired effect of decreasing patient mortality.

Assessment

The vital link between airway management education and improved patient care can be achieved by assessment and audit. This is particularly important for procedural skill training where research and application of assessment in anaesthetic procedural skill has lagged behind other specialties, such as surgery. Valid and reliable assessment has been promoted by the American Council for Postgraduate Medical Education (ACGME) in order to uphold the standards of training and ensure that doctors conduct safe practice.[20] It is recognized that systems such as log books, volume of practice and work-based assessment all have weaknesses. Development of skill takes time and individuals learn at different rates. Ideally, assessment should be reliable, valid, feasible, cost-effective and comprehensive, incorporating varying levels of difficulty.[21] Research in this area is evolving with new concepts concerning assessment of laryngoscopy skill.[22] Objective assessment of procedural skill and non-technical skill is possible through computer analysis and simulation based medical education.[23] Cumulative sum analysis (cusum) shows promise as a quality control method for assessment of trained anaesthetists or assessment of new techniques and equipment.[24]

Confidence in a colleague or trainee to carry out a critical activity, such as managing a patient with a difficult airway, requires that they possess a combination of general competencies and entrustable professional activities (EPAs) needed to perform that activity. These concepts are currently being considered for integration into curricula. It is planned to develop and audit EPAs and that these will become part of a practitioner's lifelong learning.[25]

An alternative to mandatory training

An alternative approach to mandatory CICO training is the implementation of a comprehensive airway management program. This was instigated at Johns Hopkins Hospital over a ten year period. Wide ranging initiatives included standardization of airway equipment, airway examination and preanaesthesia assessment. A formalization of the education program instituted simulation airway training and education for support staff. A multidisciplinary difficult airway response team was formed. Continuous updating of current airway technology and dissemination of critical airway information through the anaesthetic record became standard. Although it is impossible to determine which of these initiatives were effective, a retrospective audit of cricothyroidotomy rate found an annual decrease of two thirds, from six cricothyroidotomies to two after introduction of the program.[26 27]

Summary

The airway practitioner needs a repertoire of airway techniques in order to cope with the complexities of a difficult airway. Achieving an airway through front of neck access under emergency conditions may be the final pathway, but appropriate judgement and skill earlier in the patient's care could potentially avoid such a crisis. Education in airway management should reach far beyond the formative stages of training. It should be seen as an ethical obligation for all practitioners to keep up to date through lifelong learning; an obligation which should be facilitated by governing bodies mandating a comprehensive airway management training program.

Authors' contributions

Writing paper: P.A.B., J.F., E.P.O.
Revising paper: all authors

Declaration of interest

P.A.B. owns and teaches on an airway management course. He has received airway management equipment for teaching and research purposes from a number of companies including Olympus, Karl Storz, Covidien, LMA, Ambu, Parker, Welch Allyn, Cook, King Systems, Verathon and Truphatek. He also owns Airway Simulation Limited which manufactures the ORSIM bronchoscopy simulator.

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