ADVANCING TECHNOLOGY IN AIRWAY MANAGEMENT

by

Dr Cyprian Mendonca

MBBS, MD, FRCA

Thesis submitted for the degree of

Doctor of Philosophy

Warwick Medical School

University of Warwick

April 2019

CONTENTS

TABLES

FIGURES

ABBREVIATIONS

AAGBI	Association of Anaesthetists of Great Britain and Ireland
ASA	American Society of Anesthesiologists
AWS	Airway scope
CICO	Can't intubate Can't oxygenate
DAS	Difficult Airway Society
eFONA	Emergency front of neck access
ENT	Ear nose throat
FONA	Front of neck access
FOI	Fibreoptic intubation
AFOI	Awake fibreoptic intubation
FOS	Fibreoptic scope
IQR	Interquartile range
MAC	Minimum alveolar concentration
mIDS	Modified intubation difficulty scale
NAP4	National Audit Project of the Royal College of Anaesthetists and Difficult Airway Society
NBD	Neuromuscular blocking drug
SAD	Supraglottic airway device
SD	Standard deviation
TOF	Train of four
VAS	Visual analogue score
WHO	World Health Organisation

ACKNOWLEDGEMENTS

I thank Professor Gavin Perkins for supervising this thesis and Andrew Taylor for proof reading this thesis.

DECLARATION

This thesis is submitted to the University of Warwick in support of an application for the degree of Doctor of Philosophy. It has been composed by Dr Cyprian Mendonca under the supervision of Professor Gavin Perkins and has not been submitted in any previous application for any degree.

The work presented was carried out by Dr Cyprian Mendonca.

Cyprian Mendonca

15th of April 2019

ABSTRACT

This thesis presents work from seven papers on airway management. The key principle explored is safely delivering oxygen to the lungs in an anaesthetised patient. Modern technology, particularly using a miniature video camera to visualise the anatomy of the airway, has revolutionised airway management. A thorough airway assessment, anticipation of difficulty, preparedness to manage an unanticipated difficulty are all essential components of safe airway management. The Difficult Airway Society (DAS) 2015 guidelines provide a strategy to manage unanticipated difficulties with airway management. An early recognition of difficulties, communication with team members and the use of advanced techniques are emphasised in the guidelines.

Facemask ventilation is an integral skill and an essential fall-back technique for maintaining oxygenation when a supraglottic airway device or tracheal intubation fails. My paper on facemask ventilation showed that neuromuscular blockade improves facemask ventilation and, therefore, oxygen delivery prior to a tracheal intubation attempt. The DAS 2015 guidelines recognise the importance of optimum head and neck position in achieving high success rate at first attempt of laryngoscopy. My paper reassures that both the “sniffing” and neutral positions are acceptable whilst using videolaryngoscopes for tracheal intubation. In an anticipated difficulty, awake tracheal intubation enhances patient safety and I have demonstrated that videolaryngoscopes have a comparable success rate and patient acceptance to that of flexible fibrescope.

When attempts to deliver oxygen by facemask, a supraglottic airway device and tracheal intubation have failed, a ‘can’t intubate can’t oxygenate’ situation arises. This requires emergency front of neck access to deliver oxygen to the lungs. As this is a very stressful situation, regular training using simulation is essential for all anaesthetists, surgeons, operating theatre teams and physicians involved in airway management. My three papers on emergency front of neck access emphasise the role of structured training in a simulated operating theatre environment.

INTRODUCTION

Airway management is central in day-to-day anaesthetic practice. The primary aim of airway management is to deliver oxygen to the lungs. In an anaesthetised patient, failure to secure an airway may lead to hypoxic brain damage and death. It is important to recognise any difficulty in airway management so that an appropriate airway management strategy can be implemented. In addition, the anaesthetist should be prepared to manage any unanticipated difficulty that may arise during the process of airway management.

1.1 Difficult airway management: incidence and outcome

Anaesthesia is relatively safe and the risk of serious complication or death is about one per 100,000 anaesthetics.[1] The majority of the complications related to anaesthesia occur at the induction phase of anaesthesia. The routine sequence of events at induction of anaesthesia include preoxygenation, administration of intravenous anesthetic agents and securing the airway. The airway related problems can contribute to 40% of adverse events that occur during induction.[1] The outcome following a failed airway management and related complications can be catastrophic.[2–7] The fourth National Audit Project of the Royal College of Anaesthetists and the Difficult Airway Society (NAP4) reported an incidence of airway-related death or brain damage of seven per one million of general anaesthetics in the United Kingdom.[8] Therefore, the ability to secure an airway in all circumstances is an essential skill for all anaesthetists.

1.2 Airway management techniques

Following induction of anaesthesia, the airway is managed using one of the four techniques: 1. Facemask ventilation, 2. Insertion of a supraglottic airway device (SAD), 3. Tracheal intubation and 4. Direct access to airway through the cricothyroid membrane or trachea.

In most circumstances, facemask ventilation is initiated soon after induction of anaesthesia. Even in situations of rapid sequence induction, the DAS 2015 guidelines recommend gentle facemask ventilation. When a difficulty with facemask ventilation is encountered, optimum jaw thrust and the use of oropharyngeal or nasopharyngeal airways helps to improve the mask ventilation. The incidence of difficult facemask ventilation is approximately 1.4% and of impossible facemask ventilation is approximately 0.15%.[9 10] Supraglottic airway devices are used in 56% of all UK general anaesthetics.[11] The incidence of failure of insertion and ventilation through a supraglottic airway device is approximately 2%.[12]

Although SADs have been increasingly used for airway maintenance, tracheal intubation provides a definitive airway. In situations where a high inflation pressure is required for controlled ventilation, prolonged duration of surgery and surgery in positions other than a supine position, tracheal intubation is the preferred technique for securing an airway. The NAP4 census showed that the tracheal tube was the primary airway device in 38.5% of general anaesthetics in the UK.[13] Tracheal intubation can be difficult in a small proportion of patients. The incidence of failed intubation is influenced by the clinical setting and it can be as low as 1 in 2000 in the elective setting[14] and as high as 1 in 100 in the emergency department.[15]

Failure to secure the airway using facemask ventilation, a SAD or tracheal intubation results in a ‘can’t intubate can’t oxygenate’ (CICO) situation. This is an airway emergency where hypoxic brain damage and death will occur if the oxygenation is not rapidly restored. The incidence of CICO varies from 1:10,000 to 1 in 50,000.[16–18] A safe and secure airway is the most important element of anaesthetic management. Over the years there has been an increasing emphasis on preventing airway related complications and improving success in tracheal intubation.

1.3 Advancing technology

Over the last two decades, advancing technology has introduced a huge array of videolaryngoscopes (Fig. 1) into clinical practice.[19–25] This has resulted in a dramatic transformation of clinical airway management. The challenge for the present

generation of anaesthetists is keeping up with the new technology by understanding the principles and pit falls adapting to the new technology and choosing the most suitable device.[26] The role of videolaryngoscopes in the management of a difficult intubation has been well recognised and are included in the national guidelines either as a first attempt device or as an alternative device.[27–30]

Although videolaryngoscopy gives a better view of the glottic inlet as compared with direct laryngoscopy, the technical skill of laryngoscopy and intubation techniques differs from that of direct laryngoscopy.[24 31 32] The laryngoscopy and intubation are considered as single step procedures during direct laryngoscopy. However, during videolaryngoscopy these are considered as three separate steps. The first step is obtaining the optimum glottic view. The second step is delivering the tube to the glottic inlet. The third step is advancing the tracheal tube through the glottic inlet into the trachea. Failure to understand this difference may lead to increased incidence of complications and reduced compliance in using the new devices.[33–35] Therefore, the routine use of a videolaryngoscope of choice ensures familiarity with the working principles, enables understanding of the common pitfalls of the device and improves the success rate.

The additional benefits of videolaryngoscopy include a higher success rate at tracheal intubation and the ability to teach the laryngoscopy technique to students and trainees.[36,37] The anaesthetist's assistant can also observe the intubation processes; hence, they will be in a better position to perform external laryngeal manipulation to improve the success of the tracheal intubation.[37 38] As videolaryngoscopy is increasingly used, further research is needed to evaluate the failure rate, complications and morbidity associated with it.

1.4 National guidelines

The introduction of new drugs,[39] airway devices, pre-oxygenation techniques [40 41] and a better understanding of the human factors contributing to outcomes associated with airway management[42–45] led to the publication of revised guidelines in managing unanticipated difficult intubation in November 2015. Plan A of the revised DAS 2015

guidelines discusses the role of optimum preparation, pre-oxygenation, facemask ventilation and laryngoscopy technique to ensure a high first attempt success rate. The key messages from the guidelines include: thorough preoperative assessment of the airway to anticipate any difficulty, appropriate preparation along with communication within the team and taking all possible measures to avoid a difficult intubation. In particular, the guidelines emphasise avoiding a CICO situation by early decision-making to wake the patient up, as well as the use of alternate intubation and oxygenation techniques. There are four plans discussed in a step-wise approach to managing unanticipated difficult intubation (Fig. 2). A well-structured approach to airway management and the clinical application of DAS guidelines is likely to reduce the morbidity associated with airway management.

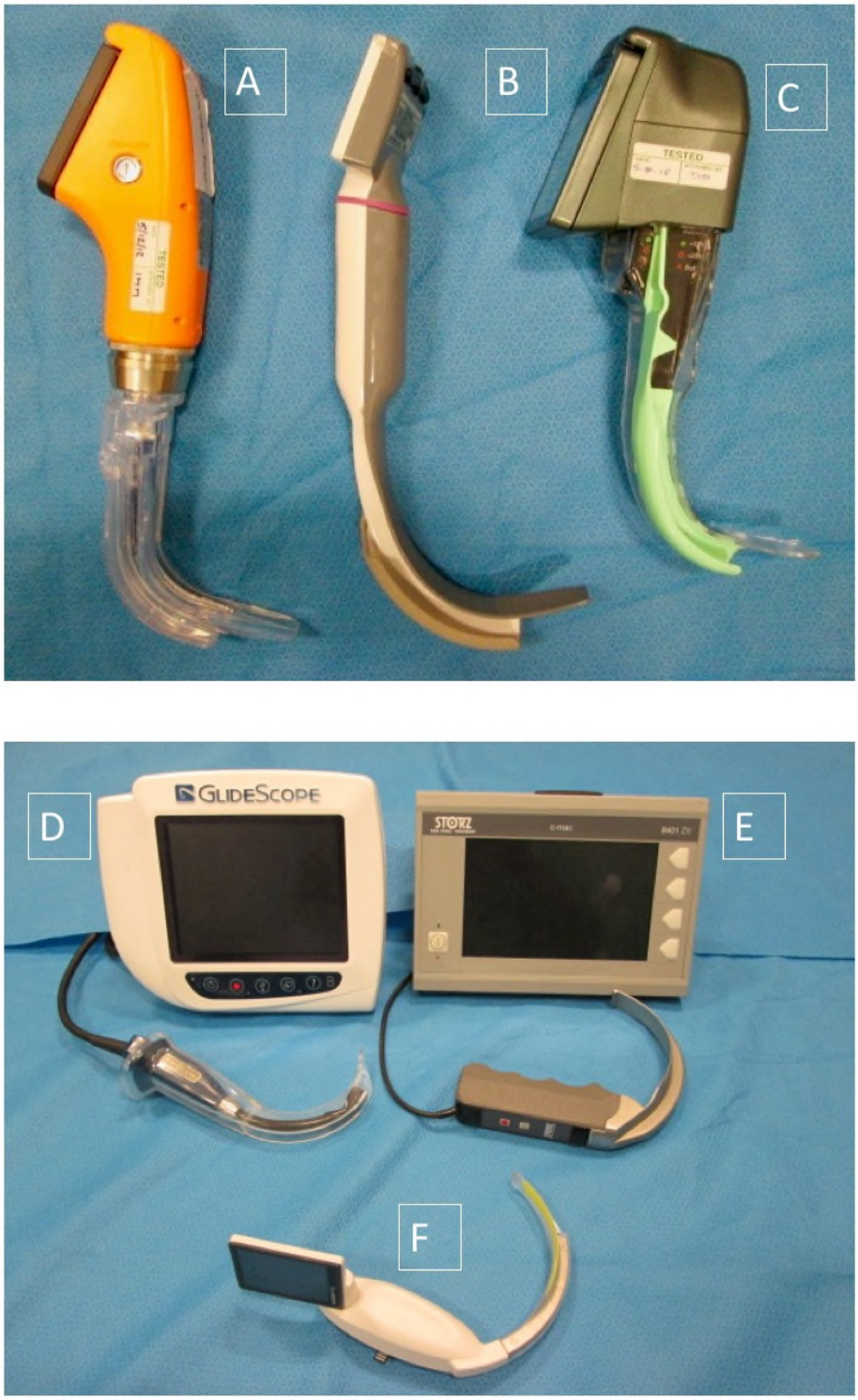


Figure 1. Channelled and non-channelled videolaryngoscopes.

A) Pentax Airway Scope®; B) KingVision®; C) Airtraq™; D) Glidescope®; E) C-MAC®; F) McGrath®.

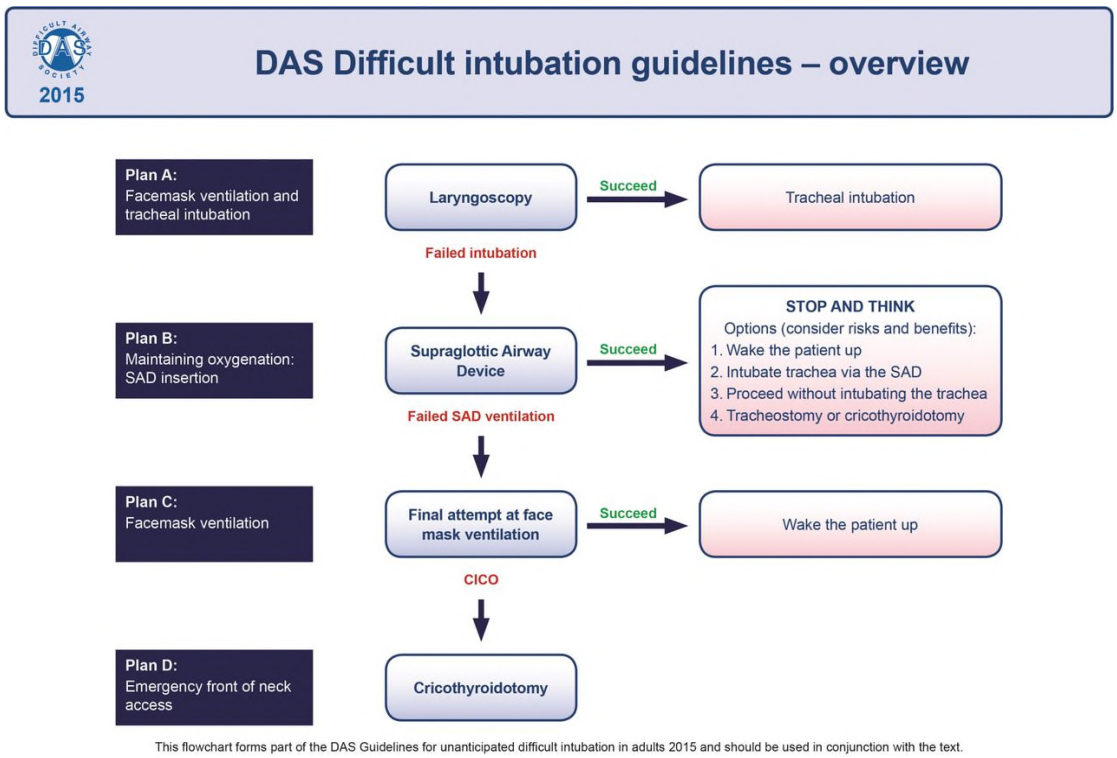


Figure 2. Difficult Airway Society difficult intubation guidelines: overview.

Reproduced from the Difficult Airway Society 2015 guidelines for the management of an unanticipated difficult intubation in adults. Frerk C, Mitchell VS, McNarry AF, et al. Difficult Airway Society intubation guidelines working group. Br J Anaesth 2015; 115: 827–848.

THESIS OVERVIEW

This thesis presents the findings from seven papers selected for my doctoral thesis submission. A brief summary of each paper is presented with the full text appearing in the appendix. The main focus is on avoiding any difficulty in airway management in the first instance and managing it if an unanticipated difficulty should arise.

- Management of an unanticipated difficult intubation (Paper 1): Difficult Airway Society 2015 guidelines for the management of unanticipated difficult intubation in adults;
- Avoiding difficulty in facemask ventilation (Paper 2): Evaluation of changes in tidal volume during facemask ventilation following administration of neuromuscular blocking drugs;
- Optimising success at videolaryngoscopy (Paper 3): A randomised clinical trial comparing the 'sniffing' and neutral position using channelled (KingVision®) and non-channelled (C-MAC®) videolaryngoscopes;
- Advances in awake intubation techniques (Paper 4): A randomised clinical trial of flexible fibrescope *versus* Pentax Airway Scope® for awake, oral tracheal intubation;
- Emergency airway rescue training (Paper 5): Comparison of cricothyroidotomy on a manikin *versus* simulator: a randomised cross over study;
- Emergency airway rescue in clinical practice (Paper 6): Front of neck access: A survey among anaesthetists and surgeons;
- Emergency airway rescue in a simulated environment (Paper 7): Effect of palpable *versus* impalpable cricothyroid membranes in a simulated emergency front-of-neck access scenario.

The first paper discusses the role of optimum preparation, good patient positioning, pre-oxygenation, facemask ventilation and laryngoscopy technique to ensure a high first attempt success rate at tracheal intubation.

Paper 2 evaluates the role of a neuromuscular blockade in improving the success of facemask ventilation. Optimum facemask ventilation is an essential component of

successful airway management. Optimising head and neck position and the use of airway adjuncts, adequate neuromuscular blockade all facilitate mask ventilation.

Paper 3 examines the effect of two different head and neck positions on videolaryngoscopy using a modified intubation difficulty scale score as an indicator of ease of tracheal intubation. Although, videolaryngoscopy has been widely used as a rescue technique for failed direct laryngoscopy it was unsure what the optimum head and neck position for videolaryngoscopy is. The results of this study re-assure the anaesthetist, either of the two positions can be used for videolaryngoscopy.

Paper 4 compares the new technique of awake intubation using a videolaryngoscope (Pentax Airway Scope®) with the established awake fibreoptic intubation. In the past, awake intubation was performed using a flexible fibrescope. The results of this paper reassure anesthetists that videolaryngoscopes are possible alternatives for flexible fibrescope for awake intubation.

Papers 5, 6 and 7 evaluate the emergency airway rescue techniques described in the DAS 2015 guidelines. Paper 5 emphasises the impact of psychological stress on emergency airway management. Paper 6 gathered the information from practicing clinicians with regard to their experience and views on emergency front of neck airway access. Paper 7 evaluated the performance of front of neck airway access in a simulated environment.

2.1 Management of unanticipated difficult intubation

Difficult Airway Society 2015 guidelines for management of unanticipated difficult intubation in adults.
Frerk CM, Mitchell VS, McNarry AF, **Mendonca C**, Bhagrath R, Patel A, O'Sullivan EP, Woodall NM, Ahmed I. British Journal of Anaesthesia 2015;115: 827-848.

This paper has been cited in 642 articles to date.

Table 1. Contribution to paper 1.

As a member of the Difficult Airway Society intubation guidelines working group, I took the lead role for the literature search. I drafted the initial list of search terms and performed the literature search on a regular basis. I screened thousands of abstracts and selected the relevant papers for detailed review by the members. I drafted the Plan A section of the guidelines paper and revised it following critical review by the co-authors. I critically reviewed the draft versions of the guidelines paper and approved the final version of the guidelines paper for submission.

Advancing technology has introduced new devices, drugs and newer techniques of oxygenation into clinical practice. Incorporating these advances and recommendations from NAP4, the existing 2004 Difficult Airway Society (DAS) guidelines[46] were revised. The aim of the guidelines was to provide a structured response to a potentially life-threatening clinical problem. They consist of a simplified single algorithm and provide a strategy to manage unanticipated difficulty with tracheal intubation during both routine and rapid sequence induction.

The DAS commissioned a working group to update the guidelines in April 2012. An initial literature search consisted of all the relevant search terms involving equipment, techniques and complications associated with elective and emergency airway management. The searches were repeated every six months. In areas where there was insufficient evidence, particularly for the Plan D section of the paper, an expert

opinion was sought. The draft guidelines were presented at DAS annual scientific meetings and opinions from DAS members were sought and reviewed. The draft guidelines were also circulated to international experts and their comments were reviewed and the final version of the paper was written.

Similar to DAS 2004 guidelines, the DAS 2015 guidelines have four plans that discusses stepwise approaches in managing unexpected difficult intubation. Plan A of the guidelines emphasises optimum preparation, pre-oxygenation, facemask ventilation and choosing an appropriate laryngoscope to ensure a high first attempt success rate. All patients must be routinely pre-oxygenated prior to induction of anaesthesia. The guidelines recommend the use of high flow nasal oxygenation, a new technique of oxygenation in patients at risk of desaturation during induction of anaesthesia. Any anticipated difficulty and airway management plans must be communicated during the team brief and sign in part of the World Health Organisation (WHO) surgical safety checklist.

When Plan A fails, the priority is to oxygenate the patient's lungs. Recently introduced second generation supraglottic airway devices are recommended in Plan B of the guidelines for this purpose. The emphasis is now shifted from tracheal intubation to oxygenation, a key safety feature of the revised DAS 2015 guidelines. This also ensures that, under stressful situations, the anaesthetist is more likely to accept other options of oxygenating the patient's lungs rather than fixating on the task of tracheal intubation.

The guidelines recognise the complications of repeated attempts at supraglottic airway devices and recommends a maximum of three attempts at supraglottic airway device insertion. A decision should be taken to move to Plan C. This is the final attempt at oxygenation using a facemask where an optimum attempt using airway adjuncts and two-person facemask ventilation is performed. If Plan C succeeds, in all circumstances with few exceptions such as lifesaving surgery, the patient should be woken up from the anaesthetic. If this final attempt at facemask oxygenation fails, it must be recognised as a CICO scenario and Plan D must be activated. At this stage, full neuromuscular blockade should be ensured.

The final step of oxygenating the patient's lungs in Plan D is *via* front of neck access (FONA). This involves a stab incision through the skin over the cricothyroid membrane (Fig. 3). In a situation where, the cricothyroid membrane is not palpable, a longitudinal skin incision is performed and, following finger dissection, cartilaginous landmarks and the cricothyroid membrane are located. Subsequently, a stab incision through the cricothyroid membrane should gain access to the airway. The blade is turned through 90°, so that the sharp edge faces caudally and gentle traction is applied to create an opening to insert the angled tip of a bougie. A well-lubricated 6.0 mm cuffed tracheal tube is then railroaded over the bougie. The cuff is inflated and ventilation commenced. The correct placement of the tube must be confirmed using capnography.

This paper adds to the existing knowledge by presenting new information on pre-oxygenation, use of videolaryngoscopy, standardised approach for managing CICO situation and the role of human factors in difficult airway management. The DAS 2015 guidelines form the skeleton for several other guidelines, research and quality improvement in the field of airway management. They are universally followed in the United Kingdom and in many institutions internationally. They have been adapted at the local level to suit the training needs of individual departments.[47] Subsequent to the publication of DAS 2015 guidelines, guidelines for the difficult and failed intubation in obstetrics,[29] guidelines for the management of tracheal intubation in critically ill patients[30] and All India Difficult Airway Society guidelines[48] were all written on similar principles and have adopted the front neck access technique from the DAS 2015 guidelines. The Scandinavian Society of Anaesthesiology and Intensive Care Medicine practice guidelines on pre-hospital management, published in 2016,[49] also refer to DAS 2015 guidelines in managing CICO situations and recommend the scalpel cricothyroidotomy technique.

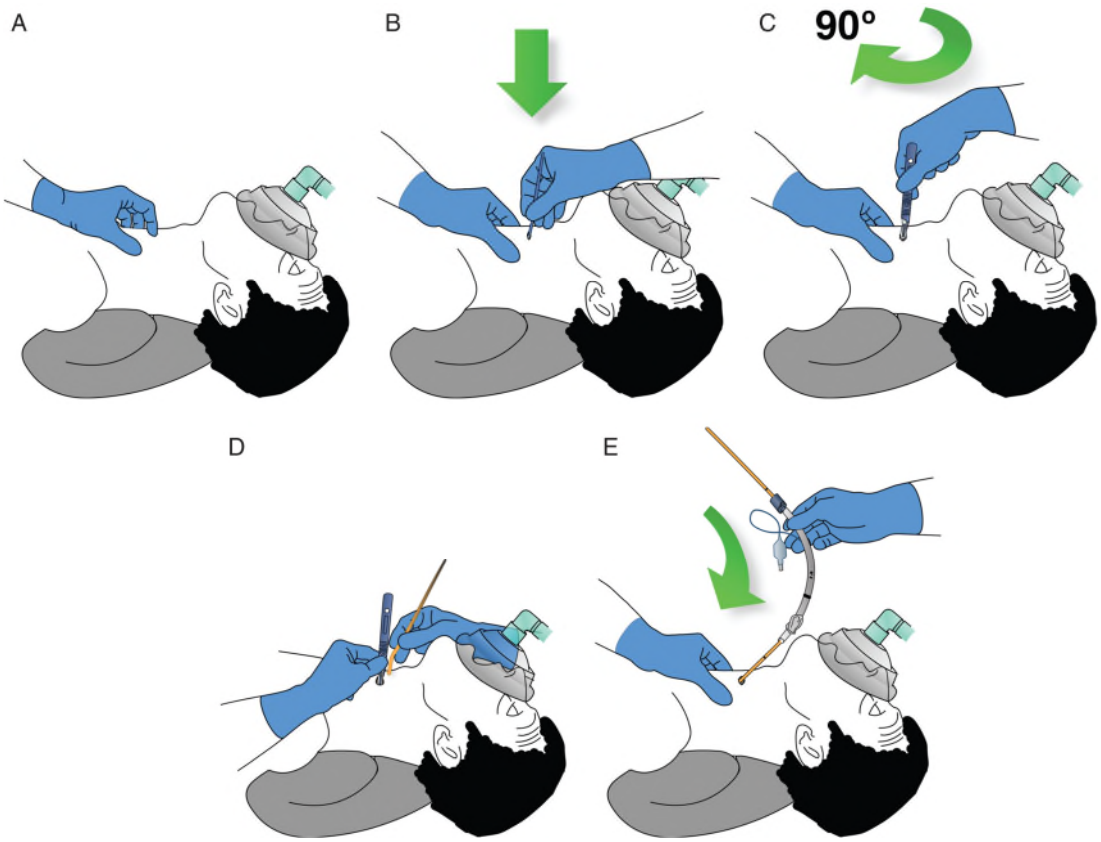


Figure 3. Cricothyroidotomy technique.

Cricothyroid membrane palpable: scalpel technique; 'stab, twist, bougie, tube'. (A) Identify cricothyroid membrane. (B) Make transverse stab incision through cricothyroid membrane. (C) Rotate scalpel so that blade edge points caudally. (D) Pulling scalpel towards you to open up the incision, slide coude tip of bougie down scalpel blade into trachea. (E) Railroad tube into trachea. Reproduced from the Difficult Airway Society 2015 guidelines for the management of an unanticipated difficult intubation in adults. Frerk C, Mitchell VS, McNarry AF, et al. Difficult Airway Society intubation guidelines working group. Br J Anaesth 2015; 115: 827–848.

Although DAS 2015 guidelines paper describes a simple algorithm, additional cognitive aids such as Vortex approach© and read aloud cards have been developed in view of further improving the outcomes in a crisis scenario.[50 51] These cognitive aids have been shown to improve the compliance with guidelines and better utilisation of the algorithms in clinical practice.[52] The Vortex approach uses a simple graphic design that depicts the three lifelines as three zones in a circular fashion around the central CICO zone (Fig. 4 and Fig. 5). The overall aim is to implement a strategy that prevents CICO.

The publication of the DAS 2015 guidelines has standardised the approach for front of neck access throughout the United Kingdom. The guidelines paper emphasises the role of regular training in managing a CICO scenario. Pairaudeau *et al.*, using simulated CICO scenarios, evaluated the performance of surgical cricothyroidotomy and showed that the anaesthetists can be trained to perform the technique to an acceptable level of competence.[53] With a view to improving the fidelity of available front of neck access training models, Berwick *et al.* developed a novel part-task trainer with improved tactile fidelity and haemorrhage making the scenario more realistic to one which occurs in clinical practice.[54]

In response to the recommendation on availability of videolaryngoscopes in all locations where tracheal intubation is performed, the majority of departments in the United Kingdom have ensured the availability of videolaryngoscopes.[55] In 2017, the Association of Anaesthetists of Great Britain and Ireland updated guidelines on Safer Pre-hospital Anaesthesia which again refer to the DAS 2015 guidelines with regard to failed intubation plans.[56] Evaluation of anterior neck anatomy to identify the cricothyroid membrane is an essential step for front of neck access. The laryngeal handshake is advocated as the first step in the DAS 2015 guidelines. This led to further research in the field of correctly identifying the cricothyroid membrane which concluded that the laryngeal handshake is more accurate than conventional palpation technique in locating the cricothyroid membrane.[57]

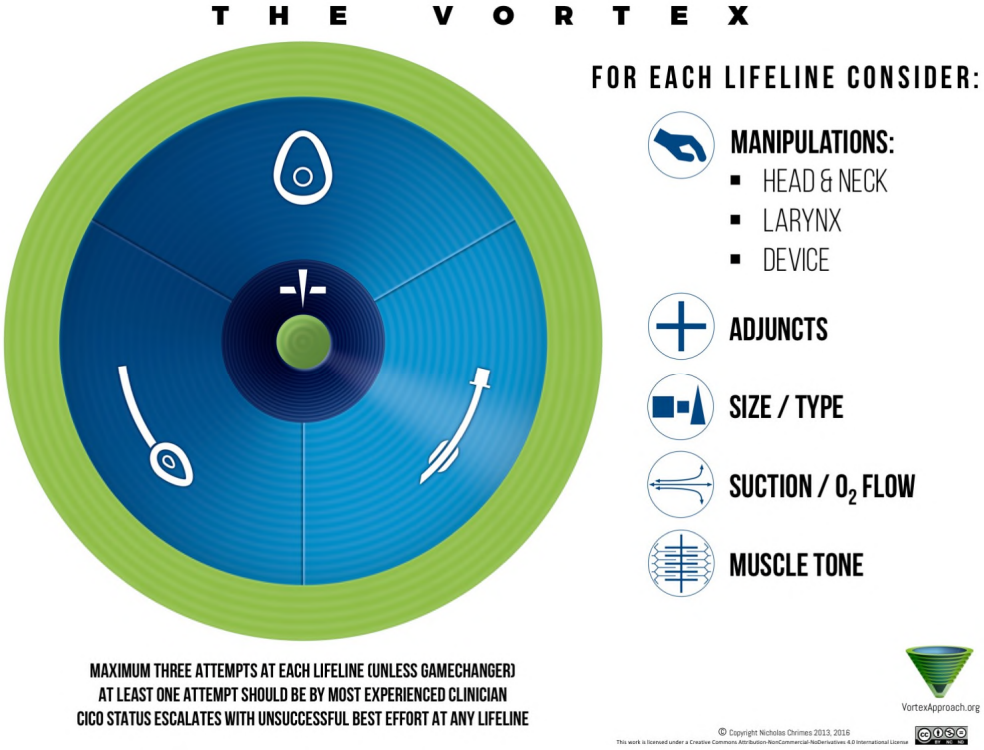


Figure 4. The Vortex implementation tool.

Reproduced from N Chrimes. The Vortex: a universal 'high-acuity implementation tool' for emergency airway management. Br J Anaesth. 2016;117: Suppl 1i20-i27.

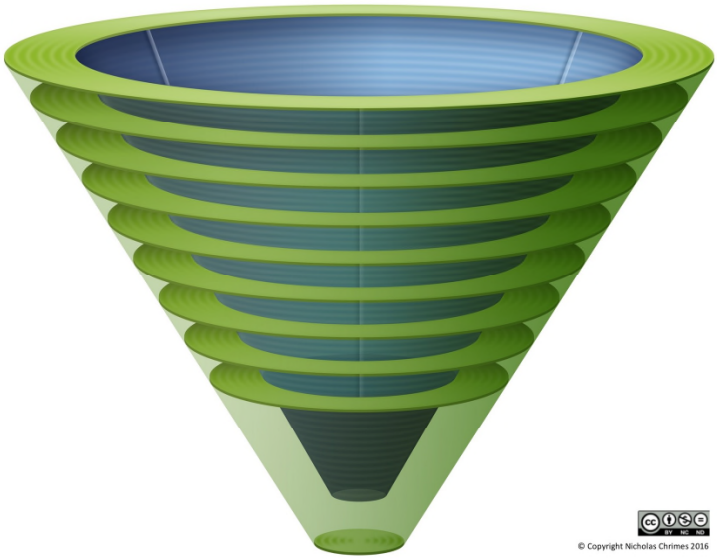


Figure 5. Lateral aspect of Vortex in three dimensions, demonstrating funnel concept. Reproduced from N Chrimes. The Vortex: a universal ‘high-acuity implementation tool' for emergency airway management. Br J Anaesth. 2016; 117: Suppl 1i20-i27.

In support of surgical cricothyroidotomy using the scalpel-bougie-tube technique as described in DAS 2015 guidelines, an editorial was jointly published in the British Journal of Anaesthesia and Clinical Otolaryngology.[58 59] Subsequent to this, McNiven *et al.* published a technical update on the surgical cricothyroidotomy (scalpel-bougie-tube technique) for ENT surgeons.[60] In the past, by custom and practice, surgical tracheostomy was considered the immediate appropriate technique for securing an airway in a CICO situation. However, both the editorial and the technical update emphasised that the scalpel-bougie-tube technique was the safest way of securing an airway and recommended training for all surgeons in this technique. Therefore, the publication of the DAS 2015 guidelines paper has resulted in a change in the technique of front of neck access at a national level.

2.2 Avoiding difficulty in facemask ventilation

Evaluation of changes in tidal volume during mask ventilation following administration of neuromuscular blocking drugs.
Sachdeva R, Kannan TR, **Mendonca C,** Patteril M. Anaesthesia 2014; 69: 826-31.

This paper has been cited in 21 articles to date.

Table 2. Contribution to paper 2.

I conducted the literature search, drafted the protocol and completed the application process for ethics approval. I worked with co-authors to collate the data, conducted the analysis and provided guidance in writing the initial draft of the paper. I critically reviewed the initial drafts and approved it for submission. Subsequently, I revised the paper following comments from peer reviewers and approved the revised manuscript for final submission.

Predicting any difficulty in airway management is an essential component of preoperative assessment. However, prediction is not perfect and clinical tests have low sensitivity.[61] Therefore, it is not always possible to predict the difficulty in mask ventilation. Hence, there has been a variation in the clinical practice of administering a neuromuscular blocking drug (NBD) at induction. The key question was whether a neuromuscular blockade facilitates mask ventilation or the resulting complete paralysis of upper airway muscles, worsening the airway obstruction and making it more difficult to mask ventilate.

With the aim of assessing the effect of NBD on mask ventilation, in this study, I compared the changes in the expired tidal volumes before and after administering the neuromuscular blocking drug during pressure-controlled ventilation. After obtaining approval from the regional ethics committee, 125 adult patients scheduled to undergo surgery under general anaesthesia and requiring tracheal intubation were recruited to the study. Patients in whom tracheal intubation was not indicated or mask ventilation

was inappropriate, patients in whom an awake intubation was indicated due to an anticipated difficult airway, children below 18 years of age and any patients with severe respiratory disease were excluded from the study.

The anaesthetic machine with integrated pressure gauge and spirometer was calibrated prior to use on each patient. Following application of standard monitoring and pre-oxygenation, general anaesthesia was induced using fentanyl and propofol. All patients were positioned in 'sniffing the morning air' position on the operating table. Facemask ventilation was commenced soon after induction using pressure-controlled ventilation at 15 cm H_2O pressure and at a rate of 12 breaths per minute. The initial grade of mask ventilation (Table 3) was assessed as described by Han *et al.*[62] An optimum jaw thrust was performed and the mask was held with both hands as tightly as possible to achieve an airtight seal and, if required, an oropharyngeal airway was inserted. Once the end-tidal concentration of isoflurane reached the minimum alveolar concentration (MAC) value of one, the expired tidal volumes with each breath were recorded for two minutes. At the end of two minutes, the neuromuscular blocking drug rocuronium 0.6 $mg.kg^{-1}$ was administered and mask ventilation was continued. Following confirmation of the onset of the neuromuscular blockade (using 'train of four' stimulation of ulnar nerve), the expired tidal volumes were recorded for another 2 minutes. Data were collected using Numbers software on the iPad 1 (2010, Apple, USA). The mean expired tidal volume before administering rocuronium, one minute and two minutes after the onset of block were compared. The mean expired tidal volumes were compared using a paired t-test. A type 1 error rate of $\alpha=0.05$ was used throughout the analysis.

All 125 participants completed the study. The results showed a significant increase in the tidal volume following administration of NBD. The mean (SD) expired tidal volume before and after administering NBD was 525 (116) ml *versus* 586 (129) ml with a mean (SD) increase in the tidal volume by 61 (13) ml ($p < 0.001$). There were 40 (32%) patients with body mass index (BMI) $\geq$ 30 $kg.m^{-2}$. A significant increase in tidal volume was also noted in this group.

I used pressure controlled ventilation to deliver a constant mean and plateau pressure and ensured an airtight seal by holding the facemask tightly throughout the study duration; therefore, changes in the tidal volume were directly related to the effect of the neuromuscular blockade.

In this study, a mean increase in tidal volume of 61 ml was noted following administration of NBD. This increase in tidal volume is clinically significant when lungs are ventilated with 100% oxygen. When ventilating at a rate of 12 breaths per minute, this will increase the minute volume by 732 ml which is nearly three times the oxygen requirement in a healthy subject.[63] This is likely to prolong the apnoea time without desaturation during subsequent tracheal intubation. During the immediate post-induction period, administration of NBD avoids the risk of laryngospasm and improves chest wall compliance which may further assist in facemask ventilation.[64 65]

Publication of my study was accompanied by an editorial which further emphasised the benefits of administering NBD prior to mask ventilation.[66] The past debate on whether to check, or not to check, the mask ventilation prior to administration of NBD has nearly come to an end. The results of my study supplement the findings from Warters *et al.* [67] which were published whilst my study was ongoing. These results have enabled practising anaesthetists to understand the role of the neuromuscular blockade on the ease of airway management. The DAS 2015 guidelines[27] and Scandinavian guidelines[48] recommend neuromuscular blockade to avoid difficulty with airway management.

In my study, I excluded patients with anticipated difficult mask ventilation, therefore, we suggested further research in patients with difficult airways. Soltesz *et al.* conducted further research in patients with anticipated difficult mask ventilation and they also demonstrated a significant improvement in the tidal volume following NBD.[68] Joeff *et al.* wished to study the side effects of mask ventilation such as deterioration of mask ventilation and associated hypoxia or difficult ventilation. They studied 210 patients and demonstrated improvements in tidal volume following the administration of NBD.[69]

In conclusion, the administration of NBD at induction of anaesthesia, facilitates mask ventilation, ensures better oxygen delivery to the lungs and reduces morbidity related to airway management.

Table 3. Grade of mask ventilation.

Reproduced from Han R, Tremper KK, Kheterpal S, O'Reilly M. Grading scale for mask ventilation. Anesthesiology 2004;101:267.

	Description
Grade 1	Ventilated by mask single handed
Grade 2	Difficult to ventilate, oropharyngeal airway inserted
Grade 3	Ventilated by mask with jaw thrust, airway manoeuvres and two handed technique
Grade 4	Unable to ventilate

2.3 Optimising success at videolarnygoscopy

A randomised clinical trial comparing the 'sniffing' and neutral position using channelled (KingVision®) and non-channelled (C-MAC®) videolaryngoscopes. **Mendonca C**, Ungureanu N, Nowicka A, Kumar P. Anaesthesia 2018; 73: 847-855.

This paper has been cited in four articles to date

Table 4. Contribution to paper 3.

I conducted the literature search, drafted the protocol and completed the IRAS application process. I recruited 70% of patients to this study. I worked with co-authors to collate the data, conducted the analysis, drafted the first version and revised it following critical review by co-authors. Subsequently, I revised it following comments from peer reviewers and approved the final version for submission.

Videolaryngoscopes have been shown to improve the laryngoscopic view and first attempt success rate of tracheal intubation.[25] The head and neck position is one of the factors that determines success of laryngoscopy and tracheal intubation.[70] Traditionally, the sniffing position has been used for direct laryngoscopy. However, the design of videolaryngoscopes and the technique of videolaryngoscopy differ from direct laryngoscopy. Therefore, the sniffing position may not be the optimum position for videolaryngoscopy. Based on my clinical experience, one of the technical difficulties with videolaryngoscopy was impingement of the tracheal tube with the anterior tracheal wall (Fig. 6). My hypothesis was that the impingement of the tracheal tube on the anterior tracheal wall is more likely to occur in the ‘sniffing’ position due to the flexion of the lower cervical spine when compared with the neutral position. We chose to study one channelled videolaryngoscope (KingVision® King Systems, Noblesville, IN, USA) and one non-channelled videolaryngoscope (C-MAC® D-blade, Karl Storz, Tuttlingen, Germany).

Following approval from the National Research Ethics Committee, adult patients of ASA physical status 1-3 and scheduled to undergo elective surgery under general anaesthesia were recruited to the study. After completion of the pre-surgical checklist and prior to induction of general anaesthesia, randomisation was revealed. Patients were allocated into one of the four study groups. The four groups were KingVision 'sniffing', KingVision neutral, C-MAC 'sniffing' and C-MAC neutral.

The primary outcome measure was ease of tracheal intubation, measured using the modified intubation difficulty scale (mIDS) score. The total mIDS score was the sum of the scores given for individual factors such as number of tracheal intubation attempts, number of operators involved, number of alternate techniques and manoeuvres used and the best laryngoscopic view obtained. The secondary outcome measures included laryngoscopy time, intubation time, laryngoscopic view and the success rate of tracheal intubation.

There were no significant differences in the mIDS score (Fig. 7), laryngoscopy time, intubation time and intubation success rate between the groups when using the KingVision® and the C-MAC® videolaryngoscopes. Therefore, either of the two positions could be used during videolaryngoscopy, if deemed advantageous for the patient.

This was the first randomised clinical trial that compared the two head and neck positions for videolaryngoscopy-aided tracheal intubation. The results reassure anaesthetists that both positions are suitable for videolaryngoscopy as dictated by the clinical situation. Although traditional teaching supports the sniffing position [27 71 72] for tracheal intubation, in situations such as cervical spine disease and suspected cervical spine injury, videolaryngoscopy and tracheal intubation can be successfully performed in the neutral position. In situations where a direct laryngoscopy has failed, a further attempt at intubation using videolaryngoscopy can be performed in the initial optimised position. In addition, to the sniffing and neutral positions, other positions used during induction of anaesthesia include 'ramped' and head elevated positions in obese patients.[73–76] The results of my study are likely to enable further research on 'ramped' and head elevated positions on the success and ease of tracheal intubation

using videolaryngoscopes. An important limitation in my study is that the procedures were carried out by experts in videolaryngoscopy. Therefore, the results may not be extrapolated to inexperienced operators and novices.

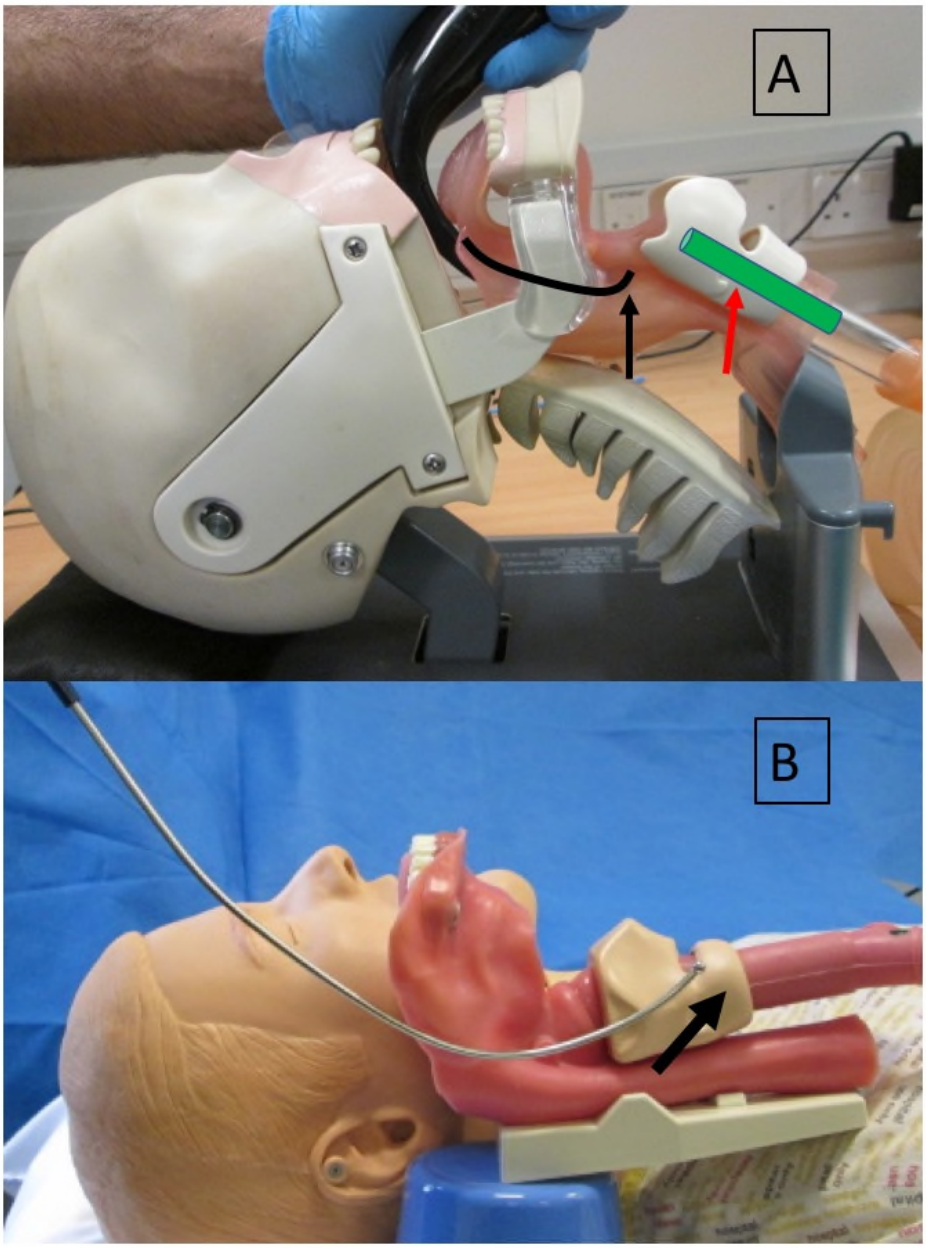


Figure 6. Anterior impingement of the tracheal tube.

(A) The tip of an angulated videolaryngoscope blade directed anteriorly (black arrow) which directs the tracheal tube toward anterior tracheal wall in relation to the tracheal axis (red arrow). (B) The curved tip of the pre-shaped stylet directed towards the anterior tracheal wall (arrow).

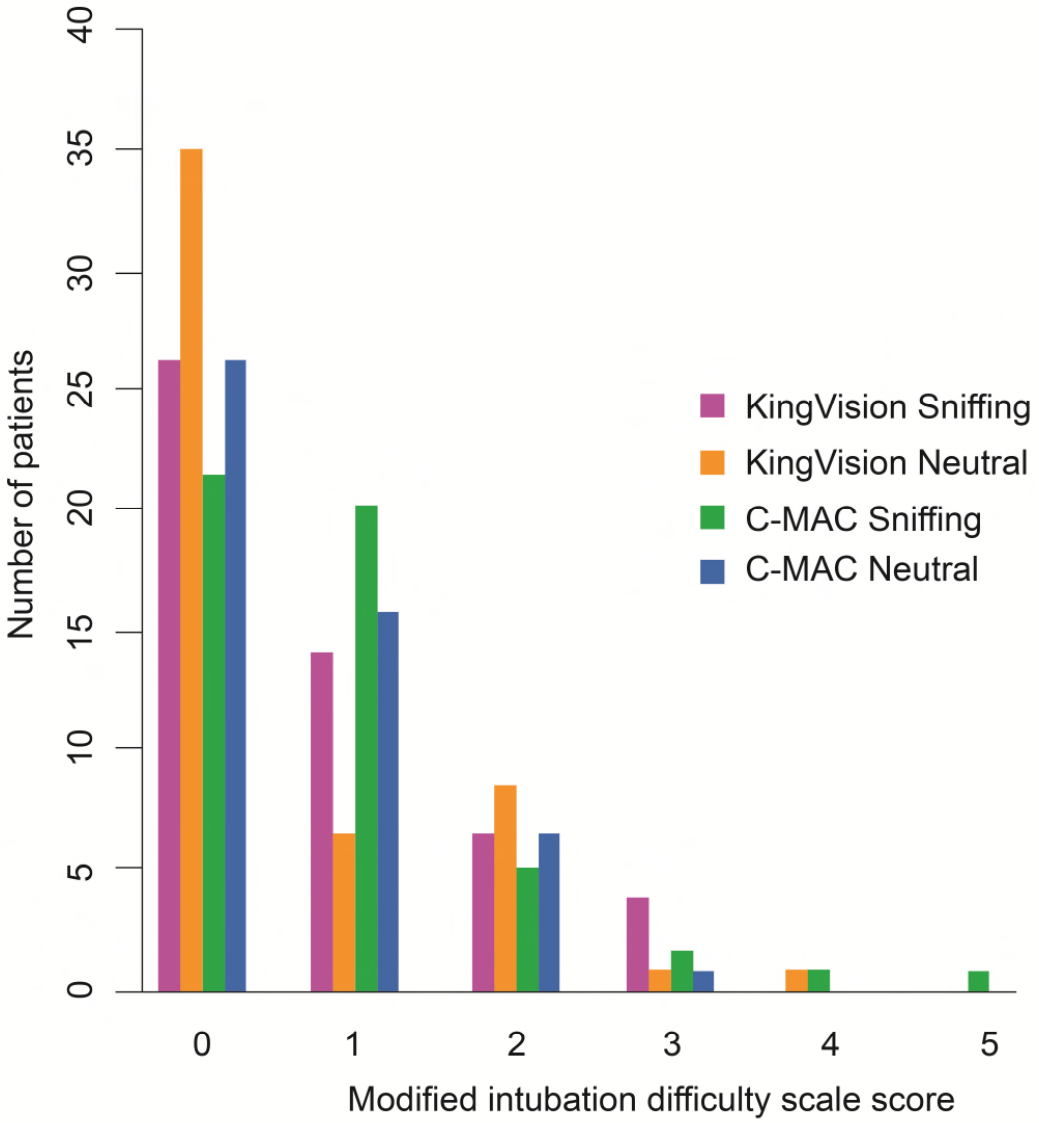


Figure 7. Distribution of modified intubation difficulty scale (mIDS) scores for all four groups.

Scores given for routine use of bougie for tracheal intubation with C-MAC is not included. Reproduced from Mendonca C, Ungureanu N, Nowicka A, Kumar P. A randomised clinical trial comparing the 'sniffing' and neutral position using channelled (KingVision®) and non-channelled (C-MAC®) videolaryngoscopes. Anaesthesia 2018; 73: 847-855.

2.4 Advances in awake intubation technique

A randomized clinical trial comparing the flexible fibrescope and the Pentax Airway Scope (AWS)® for awake oral tracheal intubation.
Mendonca C, Mesbah A, Velayudhan A, Danha R. Anaesthesia 2016; 71: 908-914.

This paper has been cited in 12 articles to date

Table 5. Contribution to paper 4.

I conducted the literature search, drafted the protocol and completed the IRAS application process. I recruited 100% of patients to this study. I worked with the co-authors to collate the data, conducted the analysis, drafted the first version and revised it following critical review by co-authors. Subsequently, I revised it following comments from peer reviewers and approved it for final submission.

The DAS 2015 guidelines discuss the role of preoperative assessment and planning. This ensures that potential airway problems are identified in advance and enables planning a strategy to reduce the risk of airway complications.

Awake tracheal intubation is the safest option in a situation where difficulty in airway management is anticipated.[8] Traditionally, awake tracheal intubation has been performed using a flexible fibrescope.[77–79] However, confidence and experience in using the flexible fibrescope scope is lacking amongst anesthetists.[8] Fibreoptic intubation is a skill that requires a high degree of manual dexterity and regular practice. At times, despite experience, it can be challenging and can be associated with complications and failure.[6 8] In addition, many anaesthetists lack the commitment and desire to master fibreoptic intubation.[80] The introduction of videolaryngoscopes into clinical practice[25 81–83] has led to a relative downward trend in fibreoptic intubation.[84]

An awake intubation can be performed using a videolaryngoscope provided the mouth opening is adequate to allow the insertion of the videolaryngoscope blade into the oral cavity.[85–88] In this study, I aimed to compare the awake fibreoptic intubation with awake intubation using a videolaryngoscope (Pentax Airway Scope®) with total procedure time as the primary outcome.

The study was approved by the National Research Ethics Committee. Forty adult patients requiring awake intubation, either due to anticipated difficult airway or scheduled to undergo cervical spine surgery, were randomly allocated to have awake intubation with either a flexible fibrescope or the Pentax Airway Scope® (Fig. 8). A standardised local anaesthetic and conscious sedation technique was used for all patients. During the procedure, total procedure time, intubation time, doses of sedation and local anaesthetic drugs used, glottic view and operator visual analogue scale score for ease of intubation were recorded. In addition, during the postoperative visit, patients were asked to score their comfort during the procedure on a 0-100 mm visual analogue scale.

This study showed that the total procedure time for awake intubation was significantly longer with flexible fibrescope as compared with the Pentax Airway Scope®, with no difference in patients' reported comfort during the procedure (Table 6). The limitation of my study being both procedures were performed by one experienced operator, the results may not be translated to less experienced operators.

The results of this study encourage anaesthetists to use videolaryngoscopes for awake tracheal intubation. This is an evolutionary step in awake intubation technique. Until recently, fibreoptic intubation was considered as gold standard for managing an anticipated difficult airway. However, for many anaesthetists, it is a challenging technique to learn[89] and regular practice is essential to retain the skill. The NAP4 identified many cases where awake fibreoptic intubation was indicated but not performed resulting in harm to these group of patients.[8] The lack of experience in using a fibrescope for awake intubation, leading to fear of failure and operator diffidence are possible reasons for this.

The results of my paper led to further study using another type of channelled videolaryngoscope (KingVision®) for awake intubation in patients with a peri-glottic tumour.[90] They achieved a 92% success rate at tracheal intubation. An awake intubation using a flexible fibrescope may lead to a 'cork-in-a-bottle' effect leading to complete airway obstruction in this group of patients.[91] The proximal view obtained through the videolaryngoscope has the added benefit of reducing airway trauma during tracheal intubation.

My findings were supported by two other studies published during the data collection and publication process of my study.[92 93] In 2018, Alhomary *et al.* published a systematic review and meta-analysis on videolaryngoscopy *versus* fibreoptic bronchoscopy for awake intubation.[94] My study is one of the five reported studies[92 93 95 96] with low risk of selection bias. Unlike others, I compared the total procedure time that has practical relevance in an awake intubation. The conclusion from my study was further echoed in this meta-analysis.

In 2018, Xue *et al.* in their review "Videolaryngoscopy in airway management: What every anesthesiologist should know!", referenced my study to emphasise the role of awake videolaryngoscopy as an alternative to awake fibreoptic intubation.[97] Wilson *et al.*, in their editorial titled "emerging role of videolaryngoscopy in airway management", referenced my findings and the technique of airway anaesthesia used in my study.[98] They concluded that awake intubation using videolaryngoscopy should be a primary technique for novice anaesthetists. The results of my study have enhanced the understanding of a new technology that ensures safe airway management. I used one type of channelled videolaryngoscope. However, there are different types of videolaryngoscopes available for clinical use.[22] Therefore, further research in this field should be focused on defining a "best videolaryngoscope" for awake tracheal intubation.

Table 6. Comparison of recorded parameters for flexible fibrescope and Pentax Airway Scope®.

Values are median (IQR [range]). Reproduced from Mendonca C, Mesbah A, Velayudhan A, Danha R. A randomized clinical trial comparing the flexible fibrescope and the Pentax Airway Scope® for awake oral tracheal intubation. Anaesthesia 2016; 71: 908-914.

	Fibreoptic intubation n=20	**Pentax Airway Scope n=20**	**p value**
Total procedure time; s	900 (739-1059 [616-1215])	651 (601-720 [498-900)	0.0001
Intubation time; s	420 (283-480 [120-608])	183 (144-220 [107-420])	0.0002
Anaesthetist's impression of ease of procedure, VAS; mm	83.6 (72-98 [49-100])	86.8 (84-91 [61-100])	0.3507
Patients' reported comfort, VAS; mm	85.5 (81-97 [69-100])	79.4 (74-85 [59-100])	0.0616

Figure 8. Flexible fibrescope and Pentax Airway Scope® with tracheal tube loaded in the channel.

2.5 Emergency airway rescue training

Comparison of cricothyroidotomy on manikin *versus* simulator: a randomised cross-over study.
John B, Suri I, Hillermann C and **Mendonca C.** Anaesthesia 2007, 62:1029-32.

This paper has been cited in 36 articles to date

Table 7. Contribution to paper 5.

I conducted the literature search, designed the structure of training sessions and drafted the protocol. I worked with the co-authors to collate the data, conducted the analysis, and drafted the first version of the paper and revised it following the critical review by co-authors. Subsequently, I revised the paper following suggestions from peer reviewers and approved it for final submission.

Cricothyroidotomy is the final step to deliver oxygen to the lungs when all other methods of airway management have failed.[27 28 46] In an emergency CICO scenario, success at the first attempt and the time taken to re-oxygenate are absolutely vital for patients' survival. Therefore, regular training in a non-clinical environment is essential.[99] However, in a non-clinical environment whilst performing cricothyroidotomy, the stress of the real life situation is not replicated. Therefore, we compared the performance of cricothyroidotomy in a simulated environment (simulator group) and in a classroom setting (manikin group) to propose the best method for future training.

A series of cricothyroidotomy training session were organised for all anaesthetists of University Hospital of Coventry and Warwickshire, Coventry. In each session, a maximum of six anaesthetists were allowed to participate. The session lasted for an hour; including a lecture and video demonstration of the procedure. At the end of the session, following written consent, they were asked to perform cricothyroidotomy twice; once on the manikin and once on the simulator. The order was randomly

allocated using sealed, opaque, numbered envelopes, such that 50% of the participants performed the procedure first on the manikin and 50% first on the simulator. The simulator was set up in a mock operating theatre with all participants dressed in operating theatre attire to provide realism to the scenario. For manikin group, same manikin was set up in a standard class room (Fig. 9). A difficult airway trolley with cricothyroidotomy equipment was available at both locations (Fig. 10). Once the participants had performed one cricothyroidotomy, they moved onto the second with very little delay.

The time taken to perform the procedure was significantly shorter in the manikin group as compared with the simulator group [34s (18) *vs* 48s (16); p =0.001]. There was no difference in the failure rate between the two groups. We also analysed the clinical experience of participants and the study showed that the higher the clinical experience, the shorter the procedure time. The simulator scenario provides a degree of realism to the operating theatre environment with a background noise of alarms and pulse oximeter tone. Therefore, the performance of cricothyroidotomy is likely to be affected by psychological stress and time pressure.

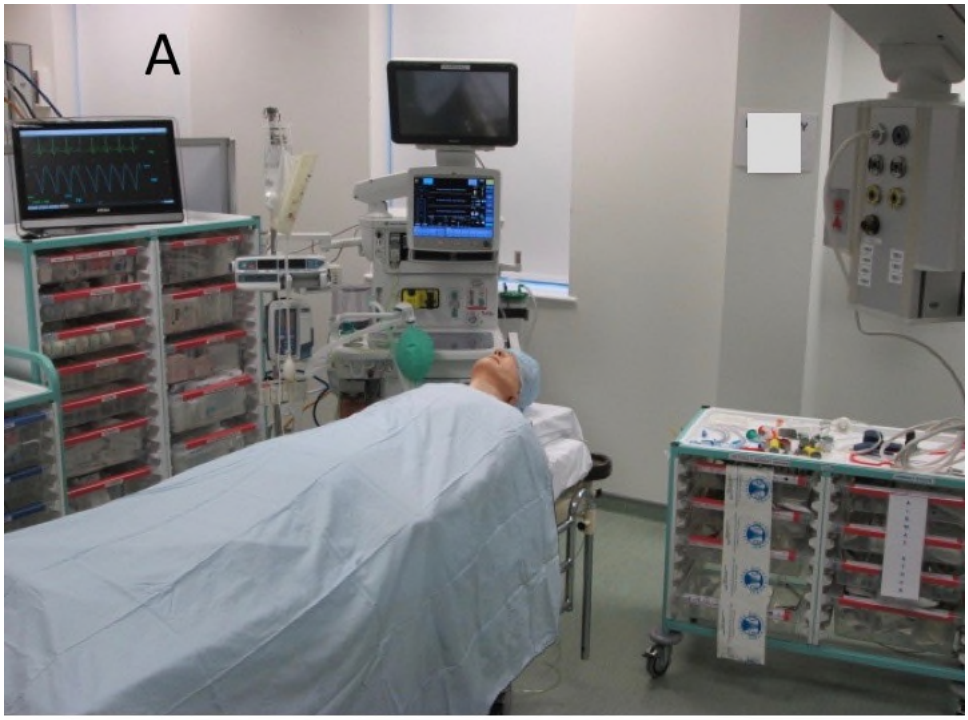
The importance of psychological stress and time pressure involved in managing a CICO scenario should be incorporated into the training. Therefore, training in a simulated clinical environment enhances the value of learning. Subsequent to my publication, Boet *et al.* studied the skill retention.[100] They also replicated simulated operating theatre environment using a high fidelity simulation and concluded that, following training in a high fidelity simulator, the skill can be retained for a minimum of one year. A review article titled "Developing technical expertise in emergency medicine -The role of simulation in procedural skill acquisition" published in 2008, has recognised the value of training procedural skills in a simulated environment.[101] Another review that evaluated paediatric cricothyroidotomy devices, discussed the relationship between the proficiency of the skill and clinical experience with reference to the results from my study.[102] The authors further emphasise the role of regular training on simulators and conclude that "it is only through training that rapid, efficient and atraumatic access to the obstructed airway can be assured." Siu *et al.* studied the effect of anaesthetists' age on performance of cricothyroidotomy using

high fidelity simulation and showed that the operator age is associated with decreased proficiency.[103] I did not objectively measure the stress levels among the participants. In 2010, Bong *et al.* showed a significant increase in heart rate and cortisol levels in the simulation group as compared with the traditional tutorial based training group.[104]

Borges *et al.* used a high fidelity simulation to reproduce real life, psychological stress and showed that debriefing significantly improves the decision making and, therefore, time to achieve ventilation.[105] Training using high fidelity simulation has shown to improve the compliance with guidelines and performance of cricothyroidotomy amongst anaesthesiology residents.[106]

Furthermore, Musbahi *et al*. in a review recommended the use of simulators for procedural skills training in otolaryngology in the hope of enhancing operating room training experience and reducing many of its challenges.[107] In 2013, Lineberry *et al.* in their review entitled "Comparative research on training simulators in emergency medicine" recommend multi-centre collaboration in simulation-based research to ensure sufficient sample size and robust methodology to strengthen inferences.[108]

The conclusion from my study is further reinforced by Petrosoniak *et al.* They observed a significant improvement in procedure time following didactic teaching with a manikin. However, two weeks later, when they repeated the procedure in a high fidelity simulation, they observed a longer time to complete the procedure.[109] Therefore, training and assessment of any rare procedural skill should take place in a high fidelity simulated environment.



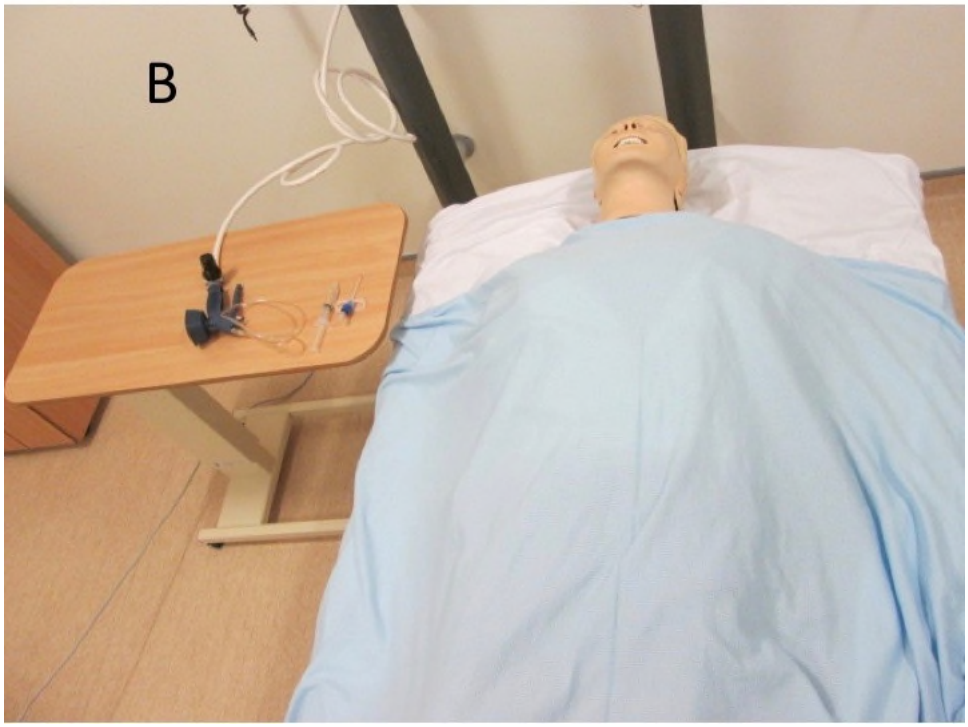


Figure 9. Simulation and class room set up for the cricothyroidotomy session.
(A) The mock operating theatre set up for simulator group and (B) the class room set up for manikin group.

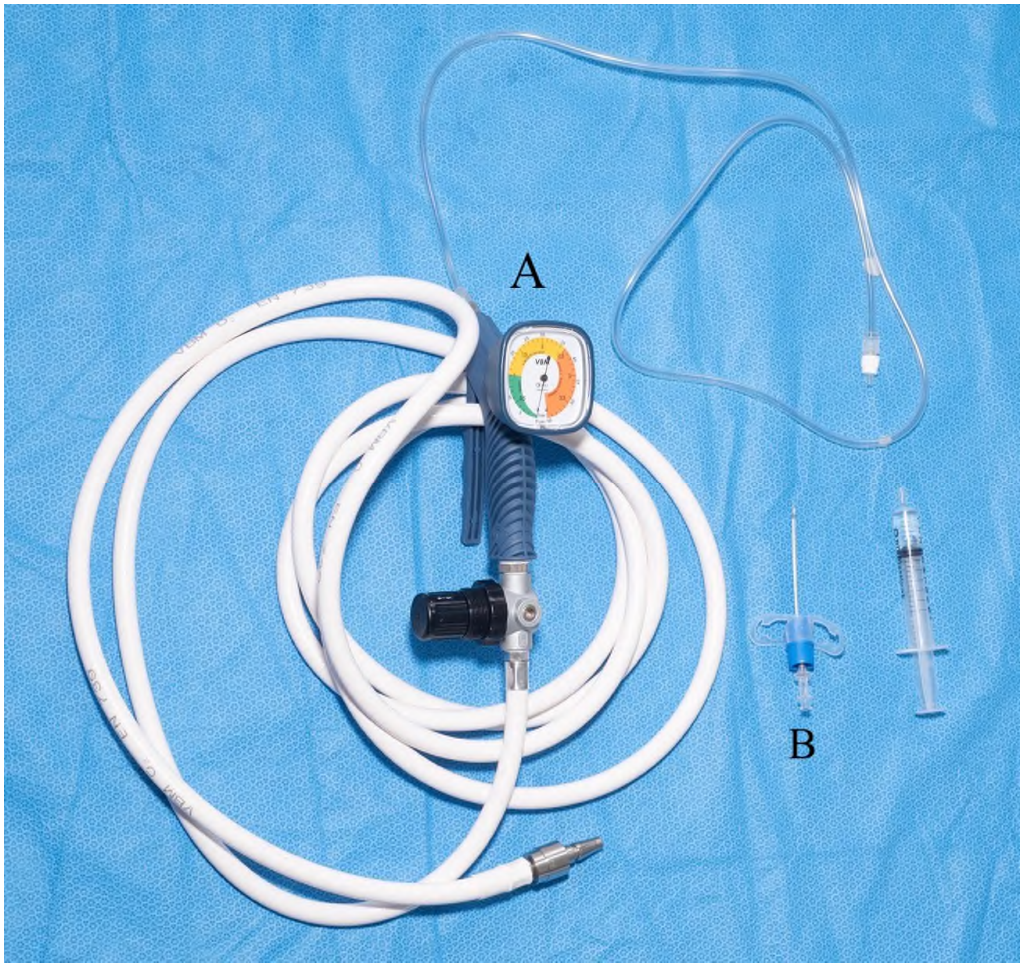


Figure 10. Equipment set up for cricothyroidotomy.

(A) Manujet Sanders injector (VBM Medizintechnik GmbH, Tutlingen, Germany) and (B) 13-G jet ventilation catheter.

2.6 Emergency airway rescue in clinical practice

Front of neck access: A survey among anesthetists and surgeons.
Mendonca C, Ahmad I, Sajayan A, Shanmugam R, Sharma M, Tosh W, Pallister E, Kimani P. J Anaesthesiol Clin Pharmacol 2017; 33:462-6.

This paper has been cited in one article up to date

Table 8. Contribution to paper 6.

I designed the survey questionnaire, conducted the literature search and drafted the protocol. I worked with co-authors to collate the data, critically reviewed the analysed results and drafted the first version of the paper and further revised it following comments from co-authors. Subsequently, I revised it following comments from peer reviewers and approved it for final submission.

Front of neck access involves a skin incision at the level of cricothyroid membrane to secure the airway in an emergency CICO situation. This is a skill that all anaesthetists should learn and practice, however vast majority of them will never have to do this procedure in their whole career. The NAP4 reports an incidence of CICO in 1:50,000 anaesthetics and analysis of a Danish anaesthesia database identified the incidence of emergency surgical airway as 3:50,000 anaesthetics.[18] Several different devices and techniques have been described for emergency front of neck airway access. Therefore, a variation in the technique between different regions and hospital specialties is expected. This will lead to different opinions and a delay in decision making in an emergency crisis situation. In view of promoting simplicity and standardised training, the 2015 DAS guidelines recommend surgical cricothyroidotomy using easily available devices (scalpel, bougie and tube) as the preferred technique. The emergency rescue of a CICO situation should be common to many hospital specialties including all surgical specialties and emergency medicine and intensive care specialists.

I surveyed surgeons and anaesthetists at multiple centres in the United Kingdom to evaluate their awareness of national guidelines, training and the preferred front of neck access technique. The survey questionnaire consisted of 17 questions related to demographics, knowledge of guidelines, training received, clinical experience, confidence in performing the technique and their knowledge on published editorials. The questionnaire was distributed at four hospitals in the UK: University Hospitals of Coventry and Warwickshire, Guy's and St Thomas', Heart of England Foundation Trust and Warwick Hospital. The survey was conducted over a two-week period as a direct interview with anaesthetists and surgeons using printed copies of the questionnaire.

One hundred and eighty-nine specialists (55% anaesthetists and 45% surgeons) were interviewed. Nearly 60% of the respondents were aware of the national guidelines. Only one third of the respondents indicated that they had received formal front of neck access training within the last year. Regarding knowledge related to the Scalpel - Bougie-Tube technique, 73% of anaesthetists and only 19% of surgeons knew the technique and had the essential equipment required to perform the technique. Although 55.5% of respondents were confident in performing this life saving technique, only 17.5% of respondents were confident in a difficult anatomy scenario where the cricothyroid membrane is not palpable.

This survey demonstrated that, despite evidence of good training for anaesthetists, there are still shortfalls in the training for surgical colleagues. Regular multi-disciplinary training in emergency front of neck access for all clinicians working with critically ill and anaesthetised patients should be encouraged.

The survey identified specific knowledge gaps and the lack of training more often among the surgeons and recommended a regular programme of multidisciplinary training at individual departmental level. This has enhanced the awareness for national guidelines and the need for structured training at departmental level. A subsequent narrative review by Onrubia *et al.*, published in 2018, referencing my paper further recommends that cricothyroidotomy should form a core skill for any physician

involved in airway management as it can make the difference between life and death.[110] Publication of training materials through Royal Colleges and DAS has led to improved training at local levels.[47]

2.7 Emergency airway rescue in a simulated environment

Effect of palpable *versus* impalpable cricothyroid membranes in a simulated emergency front-of-neck access scenario.
Pairaudeau C F, **Mendonca C,** Hillermann C, Qazi, I, Baker P A, Hodgson R E, Radhakrishna S. Anaesthesia 2018; 73: 579-586

This paper has been cited in five articles to date

Table 9. Contribution to paper 7.

I conducted the literature search, designed the structure of the training sessions and drafted the protocol. I devised the training models and worked with the co-authors to collate the data, conducted the analysis and drafted the first version of the paper and further revised it following comments from co-authors. Subsequently, I revised it following suggestions from peer reviewers and approved it for final submission.

The DAS 2015 guidelines recommend a surgical (scalpel-bougie-tube) technique for front of neck access (FONA). As described in the previous sections, this involves stab incision through the skin and cricothyroid membrane.

The success of the technique depends on the ability to identify quickly such landmarks as the thyroid cartilage, cricoid cartilage, cricothyroid membrane and the midline of the airway. In most subjects, the cricothyroid membrane is palpable. However, in situations such as short neck, morbid obesity and abnormal neck anatomy, it may be difficult to locate the front of neck anatomy and the midline. The steps described to access the airway through the front of neck in a situation where the cricothyroid membrane is impalpable, are technically challenging. Further to this, anaesthetists are not routinely trained in surgical skills such as holding the scalpel, skin incision and tissue dissection. It is of clinical interest to understand how anaesthetists would perform such a technical skill, particularly when faced with an impalpable

cricothyroid membrane. Therefore, we aimed to evaluate the proficiency with which anaesthetists can perform the technical steps described in the DAS 2015 guidelines. We also wished to study the failure rate and the time taken to perform the two different techniques.

Following approval from local Research, Development and Innovation department, all the anaesthetists at University Hospitals Coventry and Warwickshire NHS Trust were invited to take part in the study. A structured training programme to train in both techniques (palpable cricothyroid membrane and impalpable cricothyroid membrane) was designed. Following structured training, they were asked to participate in a simulated CICO scenario on a SimMan® simulator (Fig. 11). The simulator was set up so that the oxygen saturation and heart rate changes occurred in proportion to a delay in oxygenation. Both the low saturation and heart rate alarms were activated creating a realistic situation. Each participant performed cricothyroidotomy twice - once on the palpable cricothyroid model and next on the impalpable cricothyroid model. The order of how one or other models were presented was determined by block randomisation. Performance of the procedures was video-recorded and arranged in two duplicate sets. They were then assessed by two independent assessors who were not involved in the training, randomisation or the conduct of the study. These videos were scored using a skill specific checklist score. This checklist involved twelve separate steps for the palpable cricothyroid membrane and fourteen separate steps for the impalpable cricothyroid membrane model.

In total, 104 anaesthetists participated in the study. The first attempt success rate was high for both palpable and impalpable cricothyroid membrane scenarios (103 *vs* 101 out of 104). Mean (SD) procedural time was 44 (16) s and 65 (17) s for the palpable and impalpable cricothyroid membrane models, respectively ($p \leq 0.001$). The median checklist score was significantly higher, and the time taken to perform the procedure was significantly shorter in the palpable cricothyroid membrane scenario as compared with the impalpable cricothyroid membrane scenario.

In this study we demonstrated that anaesthetists with limited or no prior experience of surgical FONA can be trained to perform the techniques recommended by the DAS 2015 guidelines to a high level of competence. We also identified key technical steps

which are less likely to be performed well. These steps must be further emphasised in all future training programmes.

The results of my study are re-assuring that anaesthetists can be trained in surgical cricothyroidotomy technique. The results also showed that cricothyroidotomy takes significantly longer in an impalpable cricothyroid membrane scenario. Awareness of this amongst anaesthetists would help them to be better prepared.

A recent narrative review and an editorial recognise the simplicity and trainability of the scalpel-bougie-tube technique and stresses the importance of prior identification of the cricothyroid membrane.[110] [111] Following on from my study, Jefferson *et al*. further studied decision making in a simulated situation and showed that only 50% of anaesthetists made the correct decision to proceed to FONA.[112] The FONA technique described in the DAS guidelines generated considerable debate about topics such as: psychological barriers[113] and reluctance to perform a vertical 8 to 10 cm skin incision.[114] In a simulated environment, I demonstrated that an anaesthetist can perform a vertical skin incision. These findings further led to an ultrasound guided study to assess the length of skin incision required.[115] The minimum incision required in the extended position was 70 mm in males and 80 mm in females, commencing 30 mm above the suprasternal notch. Therefore, an 8 to 10 cm length incision as described in the DAS guidelines is adequate in all locations of the cricothyroid membrane.

A national database to collect anonymised data on FONA and regular analysis of results would be helpful in evaluating how the training in simulated environments has translated into clinical practice.

Figure 11. Front of neck access training setup.

(A) SimMan simulator (B) Crico-Trainer 'Adelaide' model (VBM Medizintechnik GmbH, Sulz am, Neckar, Germany) for palpable cricothyroid membrane scenario and (C) Crico-Trainer 'Frova' model (VBM Medizintechnik GmbH, Sulz am, Neckar, Germany) for impalpable cricothyroid membrane scenario.

DISCUSSION

Advancing technology has introduced new devices and techniques into the clinical practice. These have been incorporated into the DAS 2015 guidelines for managing an unanticipated difficult intubation. The key principles involve early recognition of difficulty and use of advanced techniques in improving patient safety in airway management.

Plan A of the DAS 2015 guidelines includes facemask ventilation and tracheal intubation. Following induction of general anaesthesia, administration of NBD ensures relaxation of laryngeal muscles and improves the success rate of tracheal intubation.[116] In addition, paralysis of respiratory muscles leads to increased chest wall compliance. All these factors enhance the safety in airway management by improving ventilation and oxygen delivery to the lungs. Warters *et al.* developed a grading scale (Warters scale) to evaluate the mask ventilation.[67] This scale includes a point system based on the manoeuvres and peak inspiratory pressure required to achieve a target 5 $ml.kg^{-1}$ tidal volume. They demonstrated a significant improvement in Warters scale following administration of NBD.

Good patient positioning improves the success of tracheal intubation. The classic sniffing position has been described as the optimum position for direct laryngoscopy using Macintosh type laryngoscopes.[71 117 118] I compared the sniffing and neutral positions for tracheal intubation using two different videolaryngoscopes. The results are encouraging, to the practicing anaesthetists, to continue further attempts at intubation in the initial, optimised position. Aziz *et al.* in a randomised clinical trial, compared two acute angled videolaryngoscopes in 1100 patients with predictors of difficult direct laryngoscopy.[70] They identified 301 tracheal intubations as difficult intubations and performed a secondary analysis to evaluate the factors leading to difficult intubation and found that the supine sniffing position is associated with a higher risk of difficult intubation. However, my study failed to confirm this. This likely due to the design of the two studies. Their study included patients with predictors of difficult intubation and, being a large multicentre study, the experience of the operator was not standardised. Anaesthetists with variable experience and grade

performed the laryngoscopy, whereas in my study all intubations were performed by three experienced anaesthetists. They defined difficult intubation based on the time taken to complete the intubation procedure (>60 seconds) whereas I used the modified intubation difficulty scale (mIDS) score which included various factors that may affect the success of tracheal intubation. Finally, there has been a difference in the definition of the neutral position. In my study, the neutral position was achieved by placing the patient supine on the operating table with no pillow under the head, whereas a standard pillow headrest was used in their study with a resulting elevation of the head.

Videolaryngoscopes look around the curve of the oropharynx and bypass the mechanical challenges of creating a direct line of sight to the laryngeal inlet. The acute angled blade of the videolaryngoscope directs the tube anteriorly, whereas in the supine position, the trachea descends into the thorax in the posterior direction. This disparity in the angle between the two, leads to impingement of the tracheal tube on the anterior wall of trachea, leading to difficulty in advancing the tube to the trachea.[32] The lateral rotation of the tracheal tube and bougie were the most common manoeuvres used to overcome the impingement in my study. Further research involving radiological imaging of tracheal alignment with the laryngotracheal angle in various head and neck positions is useful in determining the optimum position for videolaryngoscopy.

Awake tracheal intubation is the safest airway management option in an anticipated difficult intubation. In recent years, the clinical use of videolaryngoscopy has increased and flexible fibrescope use is relatively decreased.[84] Therefore, the new knowledge of using videolaryngoscopes for awake intubation is helpful in future training of advanced airway skills.

Although FONA is a lifesaving emergency procedure, the majority of anaesthetists do not have clinical experience, due to the rarity of situation. In addition, during the emergency, psychological stress slows the motor skills. Therefore, all anaesthetists, surgeons and physicians involved in airway management should receive regular training using a high-fidelity simulation. Through a national survey, I showed that the

knowledge of new guidelines was lacking amongst surgical colleagues and emphasised the role of training in teams. Subsequently, I demonstrated that through structured training, anaesthetists can perform surgical cricothyroidotomy in a simulated impalpable cricothyroid membrane situation. Following my publication, further research has been focussed on designing an appropriate model for impalpable cricothyroid membrane.[119]

The DAS 2015 guidelines form a strong foundation for clinical airway management and airway management academia. The methodology involved a robust list of search terms and criteria to retrieve all relevant publications. Opinions from DAS members, presentations at national meetings and expert consensus processes were used whilst drafting the guidelines. Although there has been a great effort and planning in disseminating the guidelines, the training resources were limited. A robust plan for multidisciplinary training would be helpful in further implementing the knowledge into clinical practice.

I evaluated the effect of neuromuscular blockade on mask ventilation, using expired tidal volume as an objective measure of improved face mask ventilation. I could have chosen the Han scale of mask ventilation.[62] However, as this is a subjective measure, I did not use it for evaluating mask ventilation. I measured and compared the tidal volumes before and after administering the NBD, therefore, blinding the anaesthetist was not possible in my study. The study methodology could have been improved by randomising patients to receive placebo and neuromuscular blockade and blinding the assessor. To avoid ethical challenge,[120] I excluded patients with characteristics of difficult mask ventilation. A subsequent study demonstrated the beneficial effects of a neuromuscular blockade in patients with anticipated difficult mask ventilation.[68]

Whilst evaluating the optimum position for videolaryngoscopy, I excluded patients with class three obesity (BMI > 40 $kg.m^{-2}$). This group of patients need further modified “ramped” position.[75] Therefore, further clinical trials looking at other positions used during laryngoscopy such as the head elevated laryngoscopy position, the ramped position and the extended head position may also be useful.

In a randomised comparison of flexible fibrescope *versus* videolaryngoscope, I studied the total procedure time (composite of sedation time, topical anaesthesia time and intubation time) in addition to patient comfort and ease of using the device. All intubations were performed by an experienced operator. Although I studied patients requiring awake intubation, due to ethical reasons [120] I did not include patients with airway pathology or patients presenting for emergency procedures. These patients may be more challenging for awake intubation so further evaluation of awake videolaryngoscopy would be beneficial. Although, I suggested a videolaryngoscope as an alternate to a flexible fibrescope for awake tracheal intubation, in patients with very limited mouth opening, a flexible fibrescope may be the only option. I studied only one videolaryngoscope (Pentax Airway Scope®) for awake intubation. As the total number of awake intubations are limited to approximately 1.7% of total general anaesthetics and 1.2% of total tracheal intubations,[79] [121] a multicentre clinical trial is needed to compare available videolaryngoscopes with flexible fibrescope.

I surveyed anaesthetists and surgeons about their knowledge and clinical practice of emergency FONA. This was limited to four hospitals in the United Kingdom. A national and international survey involving anaesthetists and surgeons would help in gaining a wider understanding of the practice and problems in training. I studied the FONA techniques on simulators. However, this differs from real life practice where difficult anatomy and bleeding are encountered. The equipment required and help were readily available in the simulated scenario which may not be the case in real life. There is a paucity of prospective studies on FONA. Due to the emergency nature and rarity of event it is not possible to conduct prospective trials on humans. In addition, the outcome of these events can be catastrophic and can have serious consequences to clinical staff and patients' families which can further limit the data capture. In obsese patients, emergency FONA access can be difficult due to increased fat tissue in the neck making it difficult to locate the cricothyroid membrane.[122] [123] Further research in this area has been focussed on designing best airway training manikins to mimic the impalpable cricothyroid membrane scenario as seen in obese patients.

An international electronic data capture system has been set up to establish the success rate of emergency FONA procedures.[124] However, this being retrospective data

reporting, is subject to certain limitations. The accuracy of the reported data is dependent on the time when it is reported. In addition, poor outcomes are less likely to be reported leading to under-reporting of the data.

The phrase: “prevention is better than cure” truly applies to airway management and particularly to the “can’t intubate can’t oxygenate” scenario. There is no single clinical test or tool that accurately predicts the difficulties in airway management. Therefore, future research should be focussed on designing an effective educational tool that ensures safe airway management. In addition, digital imaging of anatomical regions of the airway and analysing ultrasound images may have a valuable role in predicting difficulty in airway management.

REFERENCES

1. Irita K, Kawashima Y, Morita K, et al. Critical events in the operating room among 1,440,776 patients with ASA PS 1 for elective surgery. Musui 2005; 8: 939-48.
2. Bromiley M. Have you ever made a mistake. R Coll Anaesth Bull 2008; 248: 442-5.
3. Kinsella SM, Winton AL, Mushambi MC, et al. Failed tracheal intubation during obstetric general anaesthesia: a literature review. Int J Obstet Anesth 2015; 24: 356-74.
4. Nagaro T, Yorozuya T, Sotani M, et al. Survey of patients whose lungs could not be ventilated and whose trachea could not be intubated in university hospitals in Japan. J Anesth 2003; 17: 232-40.
5. Domino KB, Posner KL, Caplan RA, Cheney FW. Airway injury during Anesthesia A Closed Claims Analysis. J Am Soc Anesthesiol 1999;91:1703-11.
6. Peterson GN, Domino KB, Caplan RA, Posner KL, Lee LA, Cheney FW. Management of the Difficult Airway: a Closed Claims Analysis. J Am Soc Anesthesiol The American Society of Anesthesiologists; 2005; 103: 33-9.
7. Mort TC. Emergency tracheal intubation: complications associated with repeated laryngoscopic attempts. Anesth Analg 2004; 99: 607-13.
8. Cook TM, Woodall N, Frerk C. Major complications of airway management in the UK: Results of the Fourth National Audit Project of the Royal College of Anaesthetists and the Difficult Airway Society. Part 1: Anaesthesia. Br J Anaesth 2011;106: 617-31.
9. Kheterpal S, Han R, Tremper KK, et al. Incidence and predictors of difficult and impossible mask ventilation. Anesthesiology 2006; 105: 885-91.
10. Kheterpal S, Martin L, Shanks AM, Tremper KK. Prediction and outcomes of impossible mask ventilation: A review of 50,000 anesthetics. Anesthesiology 2009; 110: 891-7.
11. Cook T. Supraglottic airway devices. In: Cook TM, Woodall N, Frerk C, eds. Fourth National Audit Project of the Royal College of Anaesthetists and the

Difficult Airway Society. Major Complications of Airway Management in the United Kingdom. London, 2011; 86-96.

12. Cook TM. Strategies for the prevention of airway complications – a narrative review. Anaesthesia 2018; 73: 93-111.
13. Bogod D, Popat M. Tracheal intubation. In: Cook TM, Woodall N, Frerk C, eds. Fourth National Audit Project of the Royal College of Anaesthetists and the Difficult Airway Society. Major Complications of Airway Management in the United Kingdom. London, 2011; 96-104.
14. Young JRB. Difficult tracheal intubation: A retrospective study. Anaesthesia 1987; 42: 487-90.
15. Sakles JC, Laurin EG, Rantapaa AA, Panacek EA. Airway management in the emergency department: A one-year study of 610 tracheal intubations. Ann Emerg Med 1998; 31: 325-32.
16. Heard AMB, Green RJ, Eakins P. The formulation and introduction of a 'can't intubate, can't ventilate' algorithm into clinical practice. Anaesthesia 2009; 64: 601-8.
17. Tachibana N, Niiyama Y, Yamakage M. Incidence of cannot intubate-cannot ventilate (CICV): results of a 3-year retrospective multicenter clinical study in a network of university hospitals. J Anesth 2015; 29: 326-30.
18. Rosenstock C V, Nørskov AK, Wetterslev J, Lundstrøm LH, Danish Anaesthesia Database. Emergency surgical airway management in Denmark: a cohort study of 452 461 patients registered in the Danish Anaesthesia Database. Br J Anaesth 2016; 117 Suppl 1: i75-i82.
19. Thong SY, Lim Y. Video and optic laryngoscopy assisted tracheal intubation - The new era. Anaesth Intensive Care 2009; 37: 219-33.
20. Aziz M. Use of video-assisted intubation devices in the management of patients with trauma. Anesth Clin 2013; 31: 157-66.
21. Zaouter C, Calderon J, Hemmerling TM. Videolaryngoscopy as a new standard of care. Br J Anaesth 2015; 114: 181-3.
22. Pott LM, Murray WB. Review of video laryngoscopy and rigid fiberoptic laryngoscopy. Curr Opin Anaesthesiol 2008; 21: 750-8.
23. Cooper RM, Pacey JA, Bishop MJ. Cooper RM. Cardiothoracic Anesthesia, Respiration and Airway; Early clinical experience with a new

videolaryngoscope (GlideScope®) in 728 patients. Can J Anesth 2005; 52: 191-8.

24. Kelly FE, Cook TM. Seeing is believing: Getting the best out of videolaryngoscopy. Br J Anaesth 2016; 117 Suppl 1: i9-i13.
25. Lewis SR, Butler AR, Parker J, Cook TM, Smith AF. Videolaryngoscopy versus direct laryngoscopy for adult patients requiring tracheal intubation Cochrane Databse Syst Rev 2016: CD011136.
26. Ericsson KA. Deliberate practice and the acquisition and maintenance of expert performance in medicine and related domains. Acad Med 2004; 79: S70-81.
27. Frerk C, Mitchell VS, McNarry AF, et al. Difficult Airway Society 2015 guidelines for management of unanticipated difficult intubation in adults. Br J Anaesth 2015; 115: 827-48.
28. Apfelbaum JL, Hagberg CA, Caplan RA, et al. Practice guidelines for management of the difficult airway: An updated report by the American Society of Anesthesiologists task force on management of the difficult airway. Anesthesiology 2013; 118: 251-70.
29. Mushambi MC, Kinsella SM, Popat M, et al. Obstetric Anaesthetists' Association and Difficult Airway Society guidelines for the management of difficult and failed tracheal intubation in obstetrics. Anaesthesia 2015; 70: 1286-306.
30. Higgs A, McGrath BA, Goddard C, et al. Guidelines for the management of tracheal intubation in critically ill adults. Br J Anaesth 2017; 120: 32-52.
31. Van Zundert A, Pieters B, Van Zundert T, Gatt S. Avoiding palatopharyngeal trauma during videolaryngoscopy: Do not forget the blind spots. Acta Anaesthesiol. Scand 2012; 56: 532-4.
32. Levitan RM, Heitz JW, Sweeney M, Cooper RM. The complexities of tracheal intubation with direct laryngoscopy and alternative intubation devices. Ann. Emerg Med 2011; 57: 240-7.
33. Vincent RDJ, Wimberly MP, Brockwell RC, Magnuson JS. Soft palate perforation during orotracheal intubation facilitated by the GlideScope videolaryngoscope. J Clin Anesth. 2007; 19: 619-21.
34. Leong WL, Lim Y, Sia ATH. Palatopharyngeal wall perforation during Glidescope intubation. Anaesth Intensive Care. 2008; 36: 870-4.

35. Thorley DS, Simons AR, Mirza O, Malik V. Palatal and retropharyngeal injury secondary to intubation using the GlideScope(R) video laryngoscope. Ann R Coll Surg Engl. 2015; 97: e67-9.

36. O'Shea J, Thio M, Kamlin COF, et al. Videolaryngoscopy as an intubation training tool for neonatal trainees – A randomised controlled trial. Arch Dis Child 2014; 99: A50.

37. Paolini JB, Donati F, Drolet P. Review article: Video-laryngoscopy: Another tool for difficult intubation or a new paradigm in airway management? Can J Anesth 2013; 60: 184-91.

38. Kaplan MB, Ward DS, Berci G. A new video laryngoscope-an aid to intubation and teaching. J Clin Anesth 2002; 14: 620-6.

39. Tran DTT, Newton EK, Mount VAH, Lee JS, Wells GA, Perry JJ. Rocuronium versus succinylcholine for rapid sequence induction intubation. Cochrane Database Syst. Rev 2015; CD002788.

40. Tanoubi I, Drolet P, Donati F. Optimizing preoxygenation in adults. Can J Anesth 2009; 56: 449-66.

41. Patel A, Nouraei SAR. Transnasal Humidified Rapid-Insufflation Ventilatory Exchange (THRIVE): a physiological method of increasing apnoea time in patients with difficult airways. Anaesthesia 2015; 70: 323-9.

42. Capella J, Smith S, Philp A, et al. Teamwork training improves the clinical care of trauma patients. J Surg Educ 2010; 67: 439-43.

43. Greenland KB, Acott C, Segal R, Goulding G, Riley RH, Merry AF. Emergency surgical airway in life-threatening acute airway emergencies - Why are we so reluctant to do it? Anaesth Intensive Care 2011; 39: 578-84.

44. Stiegler MP, Neelankavil JP, Canales C, Dhillon A. Cognitive errors detected in anaesthesiology: a literature review and pilot study. Br J Anaesth 2012; 108: 229-35.

45. Flin R, Fioratou E, Frerk C, Trotter C, Cook TM. Human factors in the development of complications of airway management: Preliminary evaluation of an interview tool. Anaesthesia 2013; 68: 817-25.

46. Henderson JJ, Popat MT, Latto IP, Pearce AC. Difficult Airway Society guidelines for management of the unanticipated difficult intubation. Anaesthesia 2004; 59: 675-94.

47. Warnakulasuriya SR, Harvey R, Mcnarry AF. Translation of national guidelines into local practice. The Clinical Teacher 2019; 16: 1-6.
48. Myatra S, Shah A, Kundra P, et al. All India Difficult Airway Association 2016 guidelines for the management of unanticipated difficult tracheal intubation in adults. Indian J Anaesth 2016; 60: 885-98.
49. Rehn M, Hyldmo PK, Magnusson V, et al. Scandinavian SSAI clinical practice guideline on pre-hospital airway management. Acta Anaesthesiol Scand 2016; 60: 852-64.
50. Chrimes N. The Vortex: A universal 'high-acuity implementation tool' for emergency airway management. Br J Anaesth 2016; 117: Suppl 1 i20-i27.
51. Harvey R, Foulds L, Housden T, et al. The impact of didactic read-aloud action cards on the performance of cannula cricothyroidotomy in a simulated 'can't intubate can't oxygenate' scenario. *Anaesthesia* 2017; 72: 343-9.
52. Marshall SD, Mehra R. The effects of a displayed cognitive aid on non-technical skills in a simulated 'can't intubate, can't oxygenate' crisis. *Anaesthesia* 2014; 69: 669-77.
53. Pairaudeau CF, Mendonca C, Hillermann C, et al. Effect of palpable vs. impalpable cricothyroid membranes in a simulated emergency front-of-neck access scenario. Anaesthesia 2018; 73: 579-86.
54. Berwick RJ, Mercer SJ, Groom P. Evaluating the fidelity of a novel part-task trainer for emergency front of neck access training. BMJ Simul Technol Enhanc Learn 2018; 4: 101-102.
55. Cook TM, Kelly FE. A national survey of videolaryngoscopy in the United Kingdom. Br J Anaesth 2017;118: 593-600.
56. Lockey DJ, Crewdson K, Davies G, et al. Safer pre-hospital anaesthesia 2017. Anaesthesia 2017; 72: 379-90.
57. Drew T, McCaul CL. Laryngeal handshake technique in locating the cricothyroid membrane: a non-randomised comparative study. Br J Anaesth 2018; 121: 1173-8.
58. Pracy JP, Brennan L, Cook TM, et al. Surgical intervention during a Can ' t intubate Can ' t Oxygenate (CICO) Event : Emergency Front-of-neck Airway (FONA)? Br J Anaesth 2016; 117: 426-8.
59. Pracy JP, Brennan L, Cook TM, et al. Surgical intervention during a Can't

Intubate Can't Oxygenate (CICO) event: Emergency Front-of-neck Airway (FONA)? Clin Otolaryngol 2016; 41: 624-6.

60. McNiven ND, Pracy JP, McGrath BA, Robson AK. The role of scalpel-bougie cricothyroidotomy in managing emergency Front of Neck Airway access. A review and technical update for ENT surgeons. Clin. Otolaryngol 2018; 43: 791-4.
61. Roth D, Pace NL, Lee A, et al. Airway physical examination tests for detection of difficult airway management in apparently normal adult patients. Cochrane Database Syst Rev 2018: CD008874.
62. Han R, Tremper KK, Kheterpal S, O'Reilly M. Grading scale for mask ventilation. Anesthesiology 2004; 101: 267.
63. Pandit JJ, Duncan T, Robbins PA. Total oxygen uptake with two maximal breathing techniques and the tidal volume breathing technique: a physiologic study of preoxygenation. Anesthesiology 2003; 99: 841–6.
64. Bennett JA, Abrams JT, Van Riper DF, Horrow JC. Difficult or impossible ventilation after sufentanil-induced anesthesia is caused primarily by vocal cord closure. Anesthesiology 1997; 87: 1070-4.
65. Abrams JT, Horrow JC, Bennett JA, Van Riper DF, Storella RJ. Upper airway closure: a primary source of difficult ventilation with sufentanil induction of anesthesia. Anesth Analg 1996; 83: 629-32.
66. Patel A. Facemask ventilation before or after neuromuscular blocking drugs: Where are we now? Anaesthesia. 2014; 69: 811-5.
67. Warters RD, Szabo T a., Spinale FG, Desantis SM, Reves JG. The effect of neuromuscular blockade on mask ventilation. Anaesthesia 2011; 66: 163-7.
68. Soltész S, Alm P, Mathes A, Hellmich M, Hinkelbein J. The effect of neuromuscular blockade on the efficiency of facemask ventilation in patients difficult to facemask ventilate: a prospective trial. Anaesthesia 2017; 72: 1484-90.
69. Joffe AM, Ramaiah R, Donahue E, et al. Ventilation by mask before and after the administration of neuromuscular blockade: A pragmatic non-inferiority trial. BMC Anesthesiol 2015; 15:134.
70. Aziz MF, Bayman EO, Van Tienderen MM, et al. Predictors of difficult videolaryngoscopy with GlideScope or C-MAC with D-blade: Secondary

analysis from a large comparative videolaryngoscopy trial. Br J Anaesth 2016; 117: 118-23.

71. El-Orbany M, Woehlck H, Salem MR. Head and neck position for direct laryngoscopy. Anesth Analg 2011; 113: 103-9.
72. Greenland KB, Edwards MJ, Hutton NJ, Challis VJ, Irwin MG, Sleigh JW. Changes in airway configuration with different head and neck positions using magnetic resonance imaging of normal airways: A new concept with possible clinical applications. Br J Anaesth 2010; 105: 683-90.
73. Rao SL, Kunselman AR, Schuler HG, Desharnais S. Laryngoscopy and tracheal intubation in the head-elevated position in obese patients: A randomized, controlled, equivalence trial. Anesth Analg 2008; 107: 1912-8.
74. Murphy C, Wong DT. Airway management and oxygenation in obese patients. Can J Anaesth 2013 2013; 60: 929-45.
75. Ranieri D, Filho SM, Batista S, Do Nascimento P. Comparison of Macintosh and Airtraq™ laryngoscopes in obese patients placed in the ramped position. Anaesthesia 2012; 67: 980-5.
76. Cattano D, Melnikov V, Khalil Y, Sridhar S, Hagberg C a. An evaluation of the rapid airway management positioner in obese patients undergoing gastric bypass or laparoscopic gastric banding surgery. Obes Surg 2010; 20:1436-41.
77. Langford RA, Leslie K. Awake fibreoptic intubation in neurosurgery. J Clin Neurosci 2009; 16: 366-72.
78. Peiris K, Frerk C. Awake intubation. J Perioper Pract 2008; 18: 96-104.
79. El-Boghdadly K, Onwochei DN, Cuddihy J, Ahmad I. A prospective cohort study of awake fibreoptic intubation practice at a tertiary centre. Anaesthesia 2017; 72: 694-703.
80. Fiadjoe JE, Litman RS. Difficult Tracheal Intubation. Anesthesiology 2012; 116: 1181-2.
81. Mihai R, Blair E, Kay H, Cook TM. A quantitative review and meta-analysis of performance of non-standard laryngoscopes and rigid fibreoptic intubation aids. Anaesthesia 2008; 63: 745-60.
82. Asai T, Liu EH, Matsumoto S, et al. Use of the Pentax-AWS in 293 patients with difficult airways. Anesthesiology 2009; 110: 898-904.
83. Griesdale DEG, Liu D, McKinney J, Choi PT. Glidescope(®) video-

laryngoscopy versus direct laryngoscopy for endotracheal intubation: a systematic review and meta-analysis. Can J Anesth 2012; 59: 41-52.

84. Wanderer JP, Ehrenfeld JM, Sandberg WS, Epstein RH. The changing scope of difficult airway management. Can J Anaesth 2013; 60: 1022-4.

85. Kajekar P, Mendonca C. Awake intubation - Videolaryngoscope or fibreoptic scope? *J* Anesthe Clinic Res. 2011; 2: 102e.

86. Jarvi K, Hillermann C. Awake intubation with the Pentax Airway Scope-initial experience on 17 patients: Eur J Anaesthesiol 2011; 28: 235.

87. Jeyadoss J, Nanjappa N, Nemeth D. intubation using Pentax AWS videolaryngoscope after failed fibreoptic intubation in a morbidly obese patient with a massive thyroid tumour and tracheal. Anaesth Intensive Care 2011; 39: 311-2.

88. Dimitriou VK, Zogogiannis ID, Liotiri DG. Awake tracheal intubation using the Airtraq laryngoscope: a case series. Acta Anaesthesiol Scand 2009; 53: 964-7.

89. Heidegger T, Gerig HJ, Ulrich B, Schnider TW. Structure and process quality illustrated by fibreoptic intubation: Analysis of 1612 cases. Anaesthesia 2003; 58: 734-9.

90. Markova L, Stopar-Pintaric T, Luzar T, Benedik J, Hodzovic I. A feasibility study of awake videolaryngoscope-assisted intubation in patients with periglottic tumour using the channelled King Vision® videolaryngoscope. Anaesthesia 2017; 74: 512-8.

91. Mason RA, Fielder CP. The obstructed airway in head and neck surgery. Anaesthesia 1999; 54: 625-8.

92. Wahba SS, Tammam TF, Saeed AM. Comparative study of awake endotracheal intubation with Glidescope video laryngoscope versus flexible fiber optic bronchoscope in patients with traumatic cervical spine injury. Egypt J Anaesth 2012; 28: 257-60.

93. Kramer A, Müller D, Pförtner R, Mohr C, Groeben H. Fibreoptic vs videolaryngoscopic (C-MAC® D-BLADE) nasal awake intubation under local anaesthesia. Anaesthesia 2015; 70: 400-6.

94. Alhomary M, Ramadan E, Curran E, Walsh SR. Videolaryngoscopy vs. fibreoptic bronchoscopy for awake intubation. Anaesthesia 2018; 73: 1151- 61.

95. Rosenstock CV, Thøgersen B, Afshari A, Christensen AL, Eriksen C, Gätke MR. Awake fiberoptic or awake video laryngoscopic tracheal intubation in patients with anticipated difficult airway management: a randomized clinical trial. Anesthesiology 2012; 116: 1210-6.
96. Abdellatif AA, Ali MA. GlideScope videolaryngoscope versus flexible fiberoptic bronchoscope for awake intubation of morbidly obese patient with predicted difficult intubation. Middle East J Anesth 2014; 22: 385-92.
97. Xue F, Liu Y, Li H, Yang G. Videolaryngoscopy in Airway Management: What Every Anesthesiologist Should Know! J Anesth Perioper Med 2018; 5: 23-33.
98. Wilson WM, Smith AF. The emerging role of awake videolaryngoscopy in airway management. Anaesthesia 2018; 73: 1058-61.
99. Wong DT, Prabhu AJ, Coloma M, Imasogie N, Chung FF. What is the minimum training required for successful cricothyroidotomy?: a study in mannequins. Anesthesiology 2003; 98: 349-53.
100. Boet S, Borges BCR, Naik VN, et al. Complex procedural skills are retained for a minimum of 1 yr after a single high-fidelity simulation training session Br J Anaesth 2011;107: 533-9.
101. Wang EE, Quinones J, Fitch MT, et al. Developing technical expertise in emergency medicine - The role of simulation in procedural skill acquisition. Acad Emerg Med 2008; 15: 1046-57.
102. CotÉ CJ, Hartnick CJ. Pediatric transtracheal and cricothyrotomy airway devices for emergency use: Which are appropriate for infants and children? Paediatr Anaesth 2009; 19: 66-76.
103. Siu LW, Boet S, Borges BCR, et al. High-fidelity simulation demonstrates the influence of anesthesiologists' age and years from residency on emergency cricothyroidotomy skills. Anesth Analg 2010; 111: 955-60.
104. Bong CL, Lightdale JR, Fredette ME, Weinstock P. Effects of simulation versus traditional tutorial-based training on physiologic stress levels among clinicians: A pilot study. Simul Healthc 2010; 5: 272-8.
105. Borges BCR, Boet S, Siu LW, et al. Incomplete adherence to the ASA difficult airway algorithm is unchanged after a high-fidelity simulation session. Can J Anesth 2010; 57: 644-9.

106. Hubert V, Duwat A, Deransy R, Mahjoub Y, Dupont H. Effect of simulation training on compliance with difficult airway management algorithms, technical ability, and skills retention for emergency cricothyrotomy. Anesthesiology 2014; 120: 999-1008.

107. Musbahi O, Aydin A, Al Omran Y, Skilbeck C, Ahmed K. Current Status of Simulation in Otolaryngology: A Systematic Review. J Surg Educ 2017; 74: 203-15.

108. Lineberry M, Walwanis M, Reni J. Comparative research on training simulators in emergency medicine: A methodological review. Simul Healthc 2013; 8: 253–61.

109. Petrosoniak A, Ryzynski A, Lebovic G, Woolfrey K. Cricothyroidotomy in situ simulation curriculum (CRIC Study). Simul Healthc 2017; 12: 76–82.

110. Onrubia X, Frova G, Sirbello M. Front of neck access to the airway: A narrative review. Trends Anaesth Crit Care 2018; 22: 45-55.

111. Kristensen MS, Teoh WH. Front of neck: continued discovery of this anatomy essential for airway management. Br J Anaesth 2018; 120: 895-8.

112. Jefferson P, Reid G, Piechowicz E. Decision making in a cannot-intubate, cannot-oxygenate scenario. Anaesthesia 2018; 73:1171.

113. Timmermann A, Chrimes N, Hagberg CA. Need to consider human factors when determining first-line technique for emergency front-of-neck access. Br J Anaesth 2016; 117: 5-7.

114. Miller TC, Comara J, Groom P. Simulated emergency cricothyroid incision length. *Br* J Anaesth 2017; 119: 340-41.

115. Fennessy P, Drew T, Husarova V, Duggan M, McCaul CL. Emergency cricothyroidotomy: an observational study to estimate optimal incision position and length. Br J Anaesth 2018; 6: 1-6.

116. Lundstrøm LH, Duez CHV, Nørskov AK, et al. Avoidance versus use of neuromuscular blocking agents for improving conditions during tracheal intubation or direct laryngoscopy in adults and adolescents. Cochrane Database Syst Rev 2017: CD009237

117. Adnet F, Baillard C, Borron SW, et al. Randomized study comparing the ‘sniffing position’ with simple head extension for laryngoscopic view in elective surgery patients. Anesthesiology. 2001; 95: 836-41.

118. Adnet F, Borron SW, Dumas JL, Lapostolle F, Cupa M, Lapandry C. Study of the 'sniffing position' by magnetic resonance imaging. Anesthesiology 2001; 94: 83-6.

119. Le Fevre PJ, Gough C, Hearne BJ, et al. A trial comparing emergency front of neck airway performance in a novel obese-synthetic neck, meat-modified obese neck and conventional slim manikin. Anaesthesia 2019; 74: 480-7.

120. Ward PA, Irwin MG. Man vs. manikin revisited – the ethical boundaries of simulating difficult airways in patients. Anaesthesia 2016; 71:1399-403.

121. Wiles MD, Mccahon RA, Armstrong JAM. Fibreoptic intubation rates in a UK teaching hospital. Proceedings of the Anaesthetic Research Society Meeting. Br J Anaesth 2010;105 :729P

122. Gadd K, Wills K, Harle R, Terblanche N. Relationship between severe obesity and depth to the cricothyroid membrane in third-trimester non-labouring parturients : a prospective observational study. Br J Anaesth 2018; 120: 1033-9

123. Ezri T, Gewürtz G, Sessler DI, et al. Prediction of difficult laryngoscopy in obese patients by ultrasound quantification of anterior neck soft tissue. Anaesthesia 2003; 58: 1111-4.

124. Duggan LV, Lockhart SL, Cook TM, O'Sullivan EP, Dare T, Baker PA. The Airway App: exploring the role of smartphone technology to capture emergency front-of-neck airway experiences internationally. Anaesthesia 2018; 73: 703-10.

BIBLIOGRAPHY OF PUBLISHED WORK

1. **Mendonca C**, Patteril M, Athanassoglou V, Tourville C, Nowicka A. Fibre-optic guided tracheal intubation through supraglottic airway devices – a randomised comparison between I-gel® and the LMA ProtectorTM Anaesthesia 2019; 74: 203-10.

2. Desai N, Wicker J, Sajayan A and **Mendonca C**. A survey of practice of rapid sequence induction caesarean section in England. International Journal of Obstetric Anaesthesia 2018; 36: 3-10.

3. **Mendonca C**, Ungureanu N, Nowicka A, Kumar P. A randomised clinical trial comparing the 'sniffing' and neutral position using channelled (KingVision) and non-channelled (C-MAC®) videolaryngoscopes. Anaesthesia 2018; 73: 847-855.

4. Pairaudeau C F, **Mendonca C**, Hillermann C, Qazi, I, Baker P A, Hodgson R E, Radhakrishna S. Effect of palpable vs. impalpable cricothyroid membranes in a simulated emergency front-of-neck access scenario. Anaesthesia 2018; 73: 579-586.

5. **Mendonca C**, Ahmad I, Sajayan A, Shanmugam R, Sharma M, Tosh W, et al. Front of neck access: A survey among anesthetists and surgeons. J Anaesthesiol Clin Pharmacol 2017; 33: 462-6.

6. Daga V, **Mendonca C**, Choksey F, Elton J, Radhakrishna S. Anaesthetic management of a pregnant patient with multiple pterygium syndrome for elective caesarean section. Int J Obstet. Anesth 2017; 31: 96-100

7. Nowicka A, Ungureanu N, Balasubramanian S, **Mendonca C**. Tracheal extubation of patients with cervical spine injury: a case report and review of literature. Anesth Analg 2017; 8: 21–5

8. **Mendonca C,** Mesbah A, Velayudhan A, Danha R. A randomized clinical trial comparing the flexible fiberscope and the Pentax Airway Scope for awake oral tracheal intubation. Anaesthesia 2016; 71: 908-914.

9. Sajayan A, Wicker J, Ungureanu N, **Mendonca C**, Kimani PK. Current practice of rapid sequence induction of anaesthesia in the UK - a national survey. Br J Anaesth 2016; 17 Suppl 1: i69-i74.

10. Frerk C, Mitchell VS, McNarry A.F, **Mendonca C**. et al. Difficult Airway Society Guidelines for Management of Unanticipated Difficult Intubation in Adults. British Journal of Anaesthesia 2015; 115: 827-48

11. Sachdeva R, Kannan TR, **Mendonca C**, Patteril M. Evaluation of changes in tidal volume during mask ventilation following administration of neuromuscular blocking drugs. Anaesthesia 2014; 69: 826-31

12. Vaidyanath C, Sharma M, **Mendonca C**, Patteril M. Fiberoptic intubation training: comparison of three different training models. J Clin Anesth 2014; 26: 168–9

13. Khare D, Kajekar P, **Mendonca C**. Dedicated Airway Laboratory, a useful resource for videolaryngoscopy training. Eur J of Anaesthesiol 2013, 30: 228

14. **Mendonca C**. Sugammadex to rescue a can’t ventilate scenario in an anticipated difficult intubation: is it the answer? –editorial, Aneasthesia 2013; 68: 795-99

15. Hussain N, **Mendonca C**. Unanticipated Difficult Airway: Can Sugammadex Rescue can’t Intubate can’t Ventilate (CICV) Scenario? J Anesth Clin Res 2012; 3: e109

16. Velayudhan A, Paramasivan S, **Mendonca C**, Radhakrishna S, Evaluation of operating department practitioners’/circulation nurses’ role in managing a can’t

intubate can't ventilate scenario using cannula cricothyroidotomy. Eur J of Anaesthesiol 2013; 30: 136-8

17. Feizerfan A, Shanmugam R, **Mendonca C**, et al. Use of alternate laryngoscopes for managing initial tracheal intubation-a comparison of practice in UK and Rest of Europe. Anaesthesia 2012; 67:31

18. Kajekar P, **Mendonca C**. Awake Intubation - Videolaryngoscope or Fibreoptic Scope? J Anesthe Clinic Res 2011; 2: 102e.

19. Jarvi K, Hillermann C, Danha R, **Mendonca C**. Awake intubation with the Pentax Airway Scope - initial experience on 17 patients. Eur J of Anaesthesiol 2011; 28: 235

20. Jarvi K, Hillermann C, Danha R, **Mendonca C**. Awake intubation with the Pentax Airway Scope. Anaesthesia 2011; 66: 314

21. Burri NR, Jarvi K, **Mendonca C**. Use of the Venner A P Advance Video Laryngoscope for Awake Intubation in a Patient with a Fused Cervical Spine. J Anesthe Clinic Res 2012; 3:194.

22. Danha RF, Sreevathsa S, Crombie N, Hellermann C, **Mendonca C**. Positive pressure ventilation with i-gel versus LMA-Unique: A randomized comparative study. J Anesthe Clinic Res 2011; 2: 173.

23. Bradbury CL, Hillermann C, Mendonca C, Danha R. Analysis of the Learning Curve with the C-MAC Video Laryngoscope: A Manikin Study. J Anesthe Clinic Res 2011; 2: 167.

24. Kajekar P, Mendonca C. Awake Intubation - Videolaryngoscope or Fibreoptic Scope? J Anesthe Clinic Res 2011; 2:102e.

25. Hodgetts V, Danha RF, **Mendonca C**, Hillerman C. A randomized Comparison of C-MAC Videolaryngscope Versus Macintosh Laryngoscope for Tracheal Intubation. J Anesthe Clinic Res 2011; 2: 163.

26. Jarvi K, Hillermann C, Danha R, **Mendonca C**. Awake intubation with Pentax Airway Scope. Anaesthesia 2011; 66: 314

27. Billiard T, Jarvi K, **Mendonca C**, Dravid R and Radhakrishna S. The SMART course can change attitudes to simulator training and non technical skills in the anaesthesia team. Anaesthesia 2011; 66: 637-8

28. Ingram C, Kerr J, **Mendonca C**. Role of turning point technology in single best answer question practice sessions. Anaesthesia 2011; 66: 641

29. Kannan TR, **Mendonca C**. Comparison of closed versus open marking system in primary FRCA viva course at Coventry. Anaesthesia 2010; 65: 869-70

30. Kajekar P, **Mendonca C**, Gaur V. Role of ultrasound in airway management, review article. International Journal of Ultrasound and Applied Technologies in Perioperative Care, May-August 2010; 1: 17-21

31. Sreevathsa S, Linga Nathan P, John B, Danha R, **Mendonca C** Comparison of fibreoptic intubation through ILMA Versus intubation through LMA CTrach. Anaesthesia 2008; 63: 734-7.

32. John B, Suri I, Hillermann C, **Mendonca C.** Comparison of cricothyroidotomy on manikin versus simulator: a randomised crossover study. Anaesthesia 2007; 62: 1029-32

33. Ranganathan M, **Mendonca C**. Regional anaesthesia in a patient with centronuclear myopathy. Anaestesia 2007; 62: 1190

34. John B, Linga-nathan P, **Mendonca C**. Tracheal intubation through a single use laryngeal mask airway using guide wire technique: Canadian Journal of Anaesthesia 2007, 54: 775-6

35. Porter M, **Mendonca C**. Anaesthesia for caesarean section in a patient with diastropic dwarfism. International Journal of Obstetric Anaesthesia 2007; 16: 145-8

36. **Mendonca C**, Griffiths J, Ateleanu B and Collis RE. Hypotension following combined spinal –epidural anaesthesia for Caesarean section. Anaesthesia 2003; 58: 428-31

37. Adke M, **Mendonca C.** Concealed airway complication during Lefort I ostetomy. Anaesthesia 2003; 58: 294.

38. Sehgal A, **Mendonca C.** Stacy MRW. Needle phobia in a patient for urgent caesarean section. International journal of obstetric anaesthesia 2001;10: 333-4.

39. Kulemekha G, **Mendonca C**. Huntington's Chorea: use of rocuronium. Anaesthesia 2001; 56:1019.

40. **Mendonca C**, Thorpe C M. The effect of smoking on induction of anaesthesia with sevoflurane. *Anaesthesia* 2001; 56: 19-23

41. **Mendonca C**, Baguley I, Kuipers A J, King D. Lam F Y. Movement of the endotracheal tube during laparoscopic hernia repair. *Acta Anaesthesiol Scand.* 2000; 44: 517-9

42. **Mendonca C**, Lynch L. 16 year old with Left sided Pneumothorax. *Chest* 1999; 115: 881-2

APPENDICES OF PUBLISHED WORK

1. Difficult Airway Society 2015 guidelines for management of unanticipated difficult intubation in adults

4. A randomized clinical trial comparing the flexible fibrescope and the Pentax Airway Scope® for awake oral tracheal intubation

5. Comparison of cricothyroidotomy on manikin vs. simulator: a randomised cross-over study

6. Front of neck access: a survey among anaesthetists and surgeons

7. Effect of palpable vs. impalpable cricothyroid membranes in a simulated emergency front-of-neck access scenario

DECLARTION OF CONTRIBUTORS

Declaration of contributors

Paper 1

Difficult Airway Society 2015 guidelines for management of unanticipated difficult intubation in adults.

Chirs M Frerk, Vikki S Mitchell, Alistair F McNarry, Cyprian Mendonca, Ravi Bhagrath, Anil Patel, Ellen P O'Sullivan, Nick M Woodall, Imran Ahmed.

British Journal of Anaesthesia 2015;115: 827-848

As a member of DAS intubation guidelines working party, Cyprian Mendonca took the lead role for literature search. He drafted the initial list of search terms and performed literature search on a regular basis. He has screened thousands of abstracts and selected relevant papers for the detailed review by the working party members. He drafted the plan A section of the guidelines paper and revised it following critical review by co-authors. He critically reviewed the draft versions of the guidelines paper and approved the final version of the guidelines paper for submission.

Paper 2

Evaluation of changes in tidal volume during mask ventilation following administration of neuromuscular blocking drugs.

Rajneesh Sachdeva, Thogulava R Kannan, Cyprian Mendonca, Mathew Patteril

Anaesthesia 2014; 69: 826-31

Cyprian Mendonca conducted the literature search, drafted the protocol and completed IRAS application process. He worked with co-authors to collate the data, conducted the analysis and provided guidance in writing the initial draft of the paper. He critically reviewed the initial drafts and approved it for submission. Subsequently he revised it following comments from peer reviewers and approved it for final submission.

Paper 3

A randomised clinical trial comparing the 'sniffing' and neutral position using channelled (KingVision) and non-channelled (C-MAC®) videolaryngoscopes

Cyprian Mendonca, Narcis Ungureanu, Aleksandra Nowicka, Peeyush Kumar

Anaesthesia 2018; 73: 847-855.

Cyprian Mendonca conducted the literature search, drafted the protocol and completed the IRAS application process. He recruited 70% of patients to this study. He worked with co-authors to collate the data, conducted the analysis, drafted the first version and revised it following critical review by co-authors. Subsequently he revised it following comments from peer reviewers and approved the final version for submission.

Paper 4

A Randomized clinical trial comparing the flexible fibrescope and the Pentax Airway Scope® for awake oral tracheal intubation

Cyprian Mendonca, Ahmed Mesbah, Akilan Velayudhan, Ratidzo Danha

Anaesthesia 2016; 71: 908-914

Cyprian Mendonca conducted the literature search, drafted the protocol and completed the IRAS application process. He recruited 100% of patients to this study. He worked with co-authors to collate the data, conducted the analysis, drafted the first version and revised it following critical review by co-authors. Subsequently, he revised it following comments from peer reviewers and approved it for final submission.

Paper 5

Comparison of cricothyroidotomy on manikin versus simulator: a randomised cross-over study.

Billing John, Ishwinder Suri, Carl Hillermann, Cyprian Mendonca

Anaesthesia 2007, 62:1029-32

Cyprian Mendonca conducted the literature search, designed the structure of training sessions and drafted the protocol. He worked with the co-authors to collate the data, conducted the analysis, and drafted the first version of the paper and revised it following the critical review by co-authors. Subsequently, he revised the paper following suggestions from peer reviewers and approved it for final submission.

Paper 6
Front of neck access: A survey among anaesthetists and surgeons

Cyprian Mendonca, Imran Ahmad, Achuthan Sajayan, Rathinavale Shanmugam, Manu Sharma, Will Tosh, Emily Pallister, Peter Kimani
J Anaesthesiol Clin Pharmacol 2017; 33:462-6.

Cyprian Mendonca designed the survey questionnaire, conducted the literature search and drafted the protocol. He worked with co-authors to collate the data, critically reviewed the analysed results and drafted the first version of the paper and further revised it following comments from co-authors. Subsequently he revised it following comments from peer reviewers and approved it for final submission.

Paper 7

Effect of palpable vs impalpable cricothyroid membranes in a simulated emergency front-of-neck access scenario.

Charles Pairaudeau, CyprianMendonca, Carl Hillermann, Ilyas Qazi, Paul Baker, Eric Hodgson, Surahmanyan Radhakrishna

Anaesthesia 2018; 73: 579-586

Cyprian Mendonca conducted the literature search, designed the structure of training sessions and drafted the protocol. He devised the training models and worked with the co-authors to collate the data, conducted the analysis and drafted the first version of the paper and further revised it

following comments from co-authors. Subsequently, he revised it following suggestions from peer reviewers and approved it for final submission.

We undersigned agree with the assignment of contributorship outlined above

Name	**signature**
Chris Frerk Chair of DAS intubation guidelines working party	[redacted]
Rajneesh Sachdeva	[redacted]
Thogulava Kannan	[redacted]
Mathew Patteril	[redacted]
Narcis Ungureanu	[redacted]
Aleksandra Nowicka	[redacted]
Peeyush Kumar	[redacted]
Ahmed Mesbah	[redacted]
Akilan Velayudhan	[redacted]
Ratidzo Danha	[redacted]
Billing John	[redacted]
Ishwinder Suri	[redacted]

Carl Hillermann	[redacted]
Imran Ahmad	[redacted]
Achuthapillai Sajayan	[redacted]
Rathinavel Shanmugam	[redacted]
Manu Sharma	[redacted]
Will Tosh	[redacted]
Emily Pallister	[redacted]
Peter Kimani	[redacted]
Charles Pairaudeau	[redacted]
Ilyas Qazi	[redacted]
Paul Baker	[redacted]
Eric Hodgson	[redacted]
Subrahmanyam Radhakrishna	[redacted]