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Respiration and the Airway

RESPIRATION AND THE AIRWAY

The evolution of airway management – new concepts and conflicts with traditional practice

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Abstract

In the last 25 yr, there have been several advances in the safe management of the airway. Videolaryngoscopes and supraglottic airways, now in routine use by new trainees in anaesthesia, have had their genesis in the recent past. The 4th National Audit Project of the Royal College of Anaesthetists and the Difficult Airway Society published in 2011 a seminal report that has influenced airway management worldwide . Understanding how the report's recommendations were constructed and how clinical guidelines compliment rather than contradict them is important in understanding the tenets of safe airway management. Over the last 25 yr there has been an increasing understanding of the effects of human factors in anaesthesiology: we may not perform in a predictable or optimal manner when faced with unusual and threatening challenges. The place of cricoid pressure in anaesthetic practice has also evolved. Current recommendations are that it be applied, but it should be released rapidly should airway difficulty be encountered. The need to prevent hypoxaemia by preoxygenation has long been recognized, but the role of high-flow nasal oxygen in anaesthesia is now being realized and developed. Clinicians must decide how novel therapies and long-standing practices are adapted to best meet the needs of our patients and prevent harm during airway management.

Key words: airway management; laryngeal mask airway; oxygen, Inhalation therapies; intubation, endotracheal

Airway management is the cornerstone of anaesthetic practice, and virtually every anaesthetic innovation in the past 25 yr has had an impact on some aspect of airway care. Pulse oximetry, sevoflurane, remifentanil, disposable equipment, rocuronium and sugammadex have all altered clinical practice. The challenge when considering these innovations is knowing how they will effect clinical practice in the next 25 yr.

Supraglottic airway devices

Brain's description of the classic Laryngeal Mask Airway[1] (cLMA, manufactured by Bivona and initially distributed by Colgate Medical) in the *British Journal of Anaesthesia* in 1983 was not the first description of a supraglottic airway,[2] but it was and still remains a revolution in safe airway management. In Verghese and Brimacombe's 1993 study[3] the cLMA was being used in almost one third of cases with a success rate of 99.8%. They noted that fewer than 5% of patients had a laryngeal mask *in situ* for procedures lasting more than two hours. By the time of the 4th National Audit Project (NAP4), supraglottic airway devices (SADs) were being used in 56.2% of general anaesthetics.[4] In 2017, a case series described SAD use in patients for up to 11 h.[5]

Similar SADs were developed by other companies, and an entirely new nomenclature based on the seal of the mask with the oropharynx (oropharyngeal leak pressure) was created.[2 6 7] Underlining its place in safe airway management, the term

Laryngeal Mask Airway became a MeSH keyword in 1993. Brimacombe reported there were 295 articles, abstracts or chapters featuring the cLMA in 1994 alone.[2]

Supraglottic airway devices enable anaesthetists to be hands-free during a procedure, but the cLMA's success was as a result of more than its labour-saving properties. Brain stated it is likely to be 'of particular value where difficulty is experienced in maintaining the airway'. The increased interest in the potential of day surgery[8] and the availability of propofol as an emulsion in 1986 were also major contributors to the success of the device (the original description recommended its use after thiopental and alcuronium 0.2 mg kg^{-1}). By 1988 the benefit propofol offered in terms of suppression of pharyngeal and laryngeal reactivity over thiopental was reported,[8] and its use advocated.[9] Brain's contribution to anaesthetic practice has already been celebrated as the cLMA reached its 30th birthday,[10 11] and the impact of his innovation cannot be overstated. This article, however, looks forward to the next 25 years.

Amidst the technological and clinical research that underpinned the development of SADs some simpler innovations have also revolutionised anaesthetic practice. The Aintree Catheter facilitates tracheal intubation through a SAD.[12–16] It was originally described as a 'disposable plastic tube', although it was cleverly designed to be just shorter (by 3 cm) than the length of the cord on a fibrescope allowing continued manoeuvrability of the fibrescope tip.[17] A guide to its use can be found at *http://www.das.uk.com/files/AIC_abbreviated_Guide_Final_for_DAS.pdf* (accessed 7 October 2017). Supraglottic airway devices can also be used to facilitate tracheal intubation directly[18–20] and have an important role in rescuing failed intubation.[21 22] Since the manufacture of the LMA Proseal, various devices have also offered enhanced separation of the respiratory and gastrointestinal tracts. They have even been used as the primary airway for Caesarean section.[23] Although blind intubation techniques are possible through devices such as the intubating laryngeal mask,[24] reports of harm[25] and the wide availability of fibreoptic equipment in the UK,[26] have made such techniques redundant.

Examples of SAD use in 'extreme circumstances' such as a bridge to extubation in the ICU,[27] managing the airway for cardiac surgery,[28] or for surgery in the prone position both electively[29 30] and with unexpected extubation[31] are reported. Clinicians must decide when to choose a specific device, not just based on how it works, but on how likely it is to fail.[32] Individual anaesthetists must combine their knowledge of a device's performance alongside their ability to use that device effectively in each situation.

Ramachandran's study[33] of 15,795 uses of the LMA Unique reported a failure rate of 1.1%, but if an anaesthetist does around 400 cases per yr and works for 30 yr as a consultant, it will take years for one individual to generate adequate data to prove the safety profile of a single device. Cook suggested a scoring system for choosing the best SAD[34] based on seven factors from the presence of a sore throat to overall insertion success. With the perpetual advent of new devices, findings rapidly become out of date but it is the methodology that must be retained.

The Difficult Airway Society's ADEPT (Airway Device Evaluation Project Team) process[35] set out a framework whereby airway equipment should be evaluated using at least level 3b (single case control or historical control) evidence. This level of evidence could then be used to inform purchasing decisions, based on properly conducted trials rather than evaluations with small numbers. Despite interest and ongoing work in this area, a UK-based study specifically using the ADEPT methodology has yet to be published.

How then does the clinician proceed? For instance, is the LMA Protector[36] a better device than the Intubating Laryngeal Tube with Drain Tube (iLTS-D; https://www.vbm-medical.com/products/airway-management/intubating-laryngeal-tube-ilts-d/; accessed 7 October 2017)? Does the Baska Mask[37 38] with its self-sealing cuff provide a better airway than any other? Which is the best SAD to use for airway rescue after failed tracheal intubation? Is one family of devices as effective in adults and children?

Clinicians must prioritise three issues: 1. Effective oxygenation and ventilation; 2. Minimizing aspiration risk; and 3. Ability to insert the device effectively without resorting to complex methods or repeated attempts. Cost, educational opportunities and the likelihood of airway trauma also inform any choice. Regular rehearsal and clinical experience with any device will improve its utility. Brimacombe found that as many as 750 LMA insertions were required to overcome the long-term learning curve of the cLMA.[39]

Videolaryngoscopy

Many regard Jack Pacey, the vascular surgeon who invented the Glidescope[40–42] in 2001, as the father of videolaryngoscopy (VL). However, optical devices designed to facilitate difficult tracheal intubation existed before this date. Katz and Berci[43] coined the phrase Optical Stylet in 1979. Regardless of their history, videolaryngoscopes are effective. A retrospective analysis by the Multicenter Perioperative Outcomes Group[44] reported 92% success using a videolaryngoscope as a rescue device after failed intubation. A Cochrane Review[45] comparing videolaryngoscopy with direct laryngoscopy stated 'statistically significantly fewer failed intubations were reported when a videolaryngoscope was used', and 'there were fewer failed intubations in those with an anticipated difficult airway when using a videolaryngoscope'. Reassuring as these statements appear, they were made based on 38 studies with 4127 participants and six studies with 830 participants, making the average number of participants per study 108 and 138, respectively.

Studies of videolaryngoscopy generate their own issues. Studies using tracheal intubation success as their primary outcome measure require many subjects (>1,000) in each arm to effectively demonstrate superiority of one device over another, if the VLs studied are 98% - 99% effective. This need for large numbers has led to several studies that looked at surrogates of intubation difficulty, such as time to intubation,[46 47] or the success rates of novices or medical students.[48] Similarly, given the relatively low incidence of difficult intubation in the general population, studies have chosen to use manikins,[49 50] simulated difficulty,[51 52] or anticipated difficulty rather than actual difficulty. This myriad of inclusion criteria has led to some potentially conflicting results. For instance, a meta-analysis of the Pentax AWS[53] *vs* Macintosh laryngoscope in 2014 suggested that despite a superior laryngeal view, the Pentax Airway Scope provided little clinical benefit over a conventional laryngoscope.

Cook's suggestion[54] that devices should be studied sequentially from manikin to human subject has merit, although this is perhaps not directly applicable to VLs. In a meta-analysis,[55] only 13% of 'non-standard' laryngoscopes had been tested on patients with anticipated or known difficult airways. Mihai and colleagues[55] then suggested that multicentre collaborations are likely to be needed, studying known difficult patients to fully understand these devices. A taxonomy describing VLs has been developed[56] by Healy and colleagues (Fig. 1). While some parts of this are already redundant (the Ctrach, a laryngeal mask with a camera

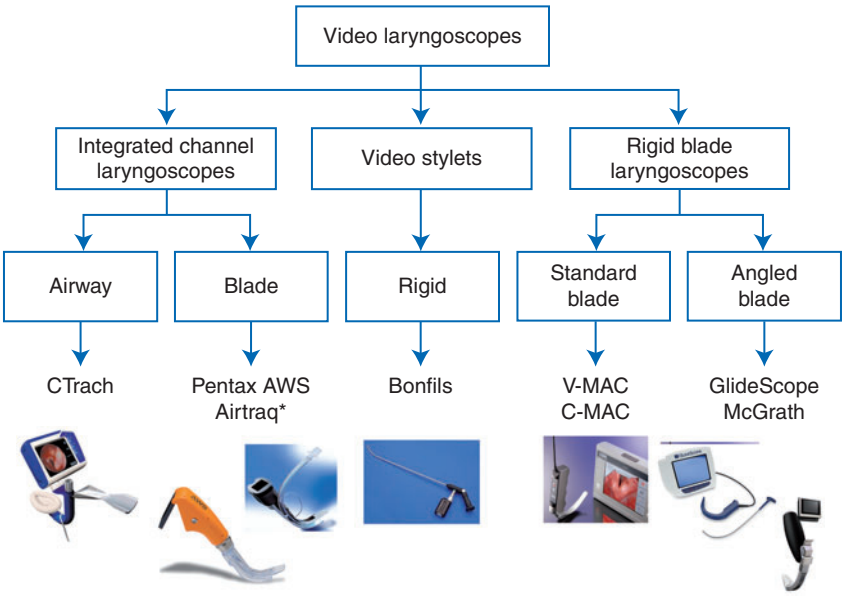

Fig 1 A classification of videolaryngoscopic devices. CTrach image courtesy of LMA North America. Pentax AWS image courtesy of Ambu USA. Airtraq image courtesy of Prodol Meditec S.A. Bonfils and C-MAC Â©2012 Photo Courtesy of KARL STORZ Endoscopy-America, Inc. GlideScope image courtesy of Verathon, USA. The McGrath series 5 image courtesy of Aircraft Medical, UK. This figure is taken from Healy et al BMC Anesthesiol. 2012; 12: 32. ©2012 Healy et al.; licensee BioMed Central Ltd. Reproduced under the terms of its Creative Commons Attribution License (2.0).

allowing visualisation of the glottis from the bowl of the device is no longer manufactured), its broad divisions into channelled, rigid video stylet, standard blade and angulated blade are useful.

Given the variety of devices available, it is not surprising that they have different features, different modes of failure and different recommendations for successful use.[57 58] A common early statement about VLs was that they offered an excellent view of the glottis but did not necessarily facilitate tracheal intubation.[59] However, this may relate more to our understanding of the process of tracheal intubation than the properties of the device itself. The idea of 'axes of alignment' was introduced by Bannister and Macbeth in 1944,[60] a year after Macintosh described his laryngoscope.[61] Greenland suggested considering this as two curves (oro-pharyngeal and pharyngo-glotto-tracheal) may be more useful[62] with VLs serving to move the eye along the primary curve. This has been disputed as the complete theory of laryngoscopy and intubation,[63] but it offers an effective way to consider videolaryngoscopy, and the shaping of a stylet or bougie should tube insertion prove difficult. This is particularly the case with hyper-angulated blades where a 60° curve is advocated.[42 64 65] However useful, these adjuncts have been known to cause trauma themselves.[66 67] With many devices now available, shaping the stylet to the shape of the blade in use may be the easiest option. Similarly, operators must not become fixated on the screen but adopt a 'patient-screen-patient' approach to observe the passage of the tracheal tube as it initially enters the oral cavity. The design of certain VLs may mean that the camera does not provide a view from the tip of the blade. This means that the best glottic view may not correspond with the best chance of passing the tracheal tube easily, and in these situations withdrawing the blade slightly may be beneficial.

The DAS 2015[21] guidelines adopted Zaouter's stance[68] recommending 'all anaesthetists should be trained to use, and have immediate access to, a videolaryngoscope', but did not specify which laryngoscope, as the evidence did not exist to recommend one over another. Proficiency with any device requires training and regular practice.[69] This is unlikely to be achieved if there are several devices across one hospital and neither trainees nor consultants are likely to become proficient in their use in such circumstances, particularly in potentially difficult airways.

After considering the evidence of efficacy, departments should choose a VL based on a variety of factors including cost of the initial device and any disposables, cleaning protocols and portability. Developing expertise will require frequent rather than exceptional use. This will enable understanding not just of how it works but recognition of those situations and airways where it may prove ineffective, as no VL is perfect.[70–72] Practice to develop, retain and be able to pass on skills is essential.

Looking to the next 25 yr, the anaesthetic community needs ongoing quality research into videolaryngoscopes, considering blade design and shape, and also how we view the role of the laryngoscope, which is not actually to view the larynx, but to facilitate tracheal intubation. Large multicentre studies will be required to establish how effective these devices are in difficult airways and whether any one is superior to another. The ultimate challenge is to be able to determine those patients where videolaryngoscopy will be ineffective before the induction of anaesthesia.

Human factors and guidelines

Alexander Pope wrote 'to err is human' in a poem in the 18th Century. The notion that humans can and do make mistakes is

longer standing than the practice of modern anaesthesia. However, in a safety critical area such as anaesthesia strategies to limit potentially catastrophic clinical errors should be embraced. In the 21st Century, anaesthetists will often cite the tragic case of Elaine Bromiley[73 74] and the outstanding, unselfish work done by her widower Martin in raising awareness of the role of human factors in anaesthetic practice. The Clinical Human Factors Group which he founded in 2007 (www.chfg.org; accessed 7 October 2017) has a vision that extends beyond safe anaesthesia, to 'a healthcare system that places an understanding of human factors at the heart of improving clinical, managerial and organisational practice leading to significant improvements in safety and efficiency'. The NAP4 report included a chapter on human factors and stated that human factors contributed to airway issues, relating to either the individual or the team, in 75 (40%) of cases. A follow up study where 12 contributing anaesthetists were interviewed, identified human factors as causative in all cases, with a median of 4.5 factors per case.[75] The RCoA's role in acknowledging and understanding the challenges of human factors predates NAP4. The first President of the new College of Anaesthetists, AA Spence, wrote an editorial in 1997 entitled 'The expanding role of simulators in risk management'.[76] He hoped that simulators would help anaesthetists in their formative years learn tricks of the mind, and operate in a more disciplined manner.

Anaesthetists are unlikely to ever train as frequently as Formula 1 pit crews, but anaesthesia is improving. The Cockpit Resource Management programmes in the aviation industry became Anaesthetic Crisis Resource Management courses, first established by Gaba in the USA.[77] Anaesthetists are recognizing that poor non-technical skills are contributory to adverse events.[78] Unfortunately, despite increased awareness, evidence suggests that Can't-Intubate, Can't-Oxygenate situations have been poorly managed.[79] The use of a graded assertiveness communication tool such as PACE (Probe, Alert, Challenge, Emergency), adapted from the aviation industry,[80] may be of benefit in averting an airway catastrophe. For effective use, everyone involved must understand how it works, and have the knowledge to know when to deploy it.[81] By 2016, Merry noted events leading to harm during anaesthesia often result from omission of key planning steps (such as failure to anticipate and plan for a difficult airway) or other forms of basic oversight.[82]

Difficult airway society guidelines

The original Difficult Airway Society (DAS) guidelines were not the first to suggest a method of dealing with a failed intubation. Tunstall described a Failed Intubation Drill for obstetrics in 1976.[83] Many of his themes still resonate in current guidelines such as the decision to abandon repeat attempts at intubation being made promptly, asking the surgeon and the theatre sister to unscrub and help, and releasing cricoid pressure. The first set of DAS Guidelines (for the management of the unanticipated difficult airway)[84] were begun in 1999 and set out to provide a step-wise series of plans to remedy the situation when the primary intubation plan failed. Although they set out to be simple, clear and definitive, when the time came to update them, one ambition was to simplify them further and make them even more didactic.

To date DAS has produced guidelines on unanticipated difficulty with intubation (2004[84] and 2015[21]), extubation,[85] paediatrics,[86] and obstetrics,[87] with guidelines for the management of the difficult airway in critical care in preparation. They do not claim to be and are not perfect, and they are not designed to dictate practice, coming with a disclaimer to this effect. They distil the evidence from published literature, national and international expert opinion, and the entire DAS membership to support best practice in airway management, including a demand to wake the patient up if appropriate. The guidelines should at least serve to stimulate an anaesthetist into developing more than one airway management plan for their patient, which they then must communicate with their team.

The guidelines were specifically written to support UK and Ireland based practice and should be read in that way, although they are used throughout the world. Other countries have already published their own guidelines. Figure 2 shows an airway trolley designed to comply with the unanticipated difficult intubation guidelines, also serving as a cognitive aid to the guidelines. Figure 3 shows some of the many devices currently available on these trolleys.

NAP4

Any consideration of airway management in the past 25 yr must include the detailed findings of the NAP4 report.[4 88] It is the largest audit of serious airway complications in the world literature. It was a prospective study of all the major airway events occurring in operating theatres, ICU or the emergency department that resulted in serious harm occurring across the UK in a 12 month period, beginning September 2008. For inclusion, complications of airway management had to have led to death, brain damage, the need for an emergency surgical airway (front of neck access), unanticipated ICU admission or prolonged ICU stay. Each included case was then reviewed by an expert panel. One hundred and eighty-four cases were reported, including 38 deaths.

The report generated 167 recommendations, divisible into recommendations for the institution, for the department, and for the individual practitioner. The recommendations complement the guidelines even though they were created as recommendations from 'non-ideal practice' rather than literature review. NAP4 identified several recurring themes including poor airway assessment, poor planning in the face of potential difficulty, a failure to plan for failure, and the inappropriate use or lack of use of various pieces of airway equipment. The obese and those with head and neck pathology featured too commonly, and poor judgment and a lack of education and training were contributory.

In recent years, anaesthetic departments have been inundated with guidelines and recommendations on airway management. Every anaesthetist must individually develop a plan that will effectively oxygenate their patient. Departments must ensure that the equipment and training is provided not just for anaesthetists but for the entire operating theatre team to facilitate effective airway management. The RCoA and DAS must strive towards better airway management at local and national levels with audit and research into best practice.

Cricoid pressure

The application of cricoid pressure to reduce gastric insufflation and regurgitation and to prevent pulmonary aspiration in those at risk is an integral part of anaesthetic practice. It was originally described in 1961 by Sellick (The Middlesex Hospital, London) as a 'simple manoeuvre' to cause 'occlusion of the upper oesophagus by backwards pressure on the cricoid ring against the bodies of the cervical vertebrae'.[89] In his original paper, Sellick reported instillation of water at pressures of up to

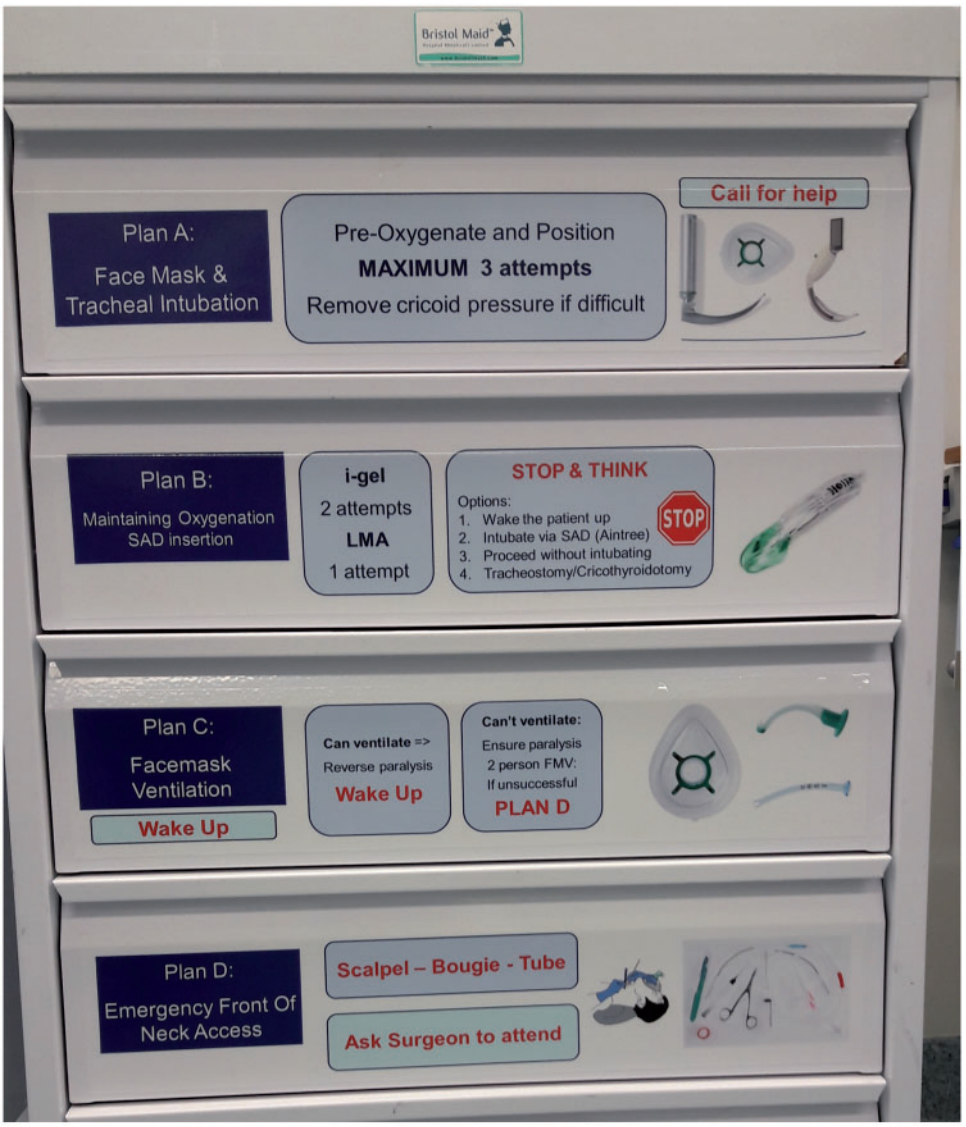

Fig 2 An airway trolley drawer-front combining airway equipment to manage an unanticipated difficult tracheal intubation with a cognitive aid to the DAS 2015 Guidelines.

100 cm H_2O into the stomach of cadavers in a steep Trendelenburg position and found that cricoid pressure prevented water from regurgitating into the pharynx. In a paralysed, anaesthetised patient with a latex tube filled with contrast placed in the oesophagus, he found the application of cricoid pressure led to a loss of contrast at the level of the applied pressure. He then went on to study cricoid pressure in patients considered at high risk for aspiration. In a series of 26 patients no regurgitation occurred in 23 before or after the application of cricoid pressure. In three patients he witnessed regurgitation after cricoid pressure was released after tracheal intubation.[89]

Anatomically the formation of a barrier appeared to provide a good reason for using cricoid pressure in high-risk patients, and the practice was quickly and widely adopted across the anaesthetic community with minimal further research, becoming an integral part of the rapid sequence induction/intubation technique for almost 50 yr.[90] Over the last 25 yr we have gained a better understanding of the factors that influence the efficacy of cricoid pressure as described by Sellick. These include the risk of pulmonary aspiration, whether a force applied to the cricoid reduced these risks, the reliability of oesophageal occlusion, optimal manual delivery of cricoid pressure, and a recognition that application of cricoid pressure itself can interfere with all aspects of airway management.

Anatomy of hypopharyngeal/oesophageal compression

The position of the oesophagus relative to the cricoid ring in the axial plane was assumed by Sellick to be immediately posterior

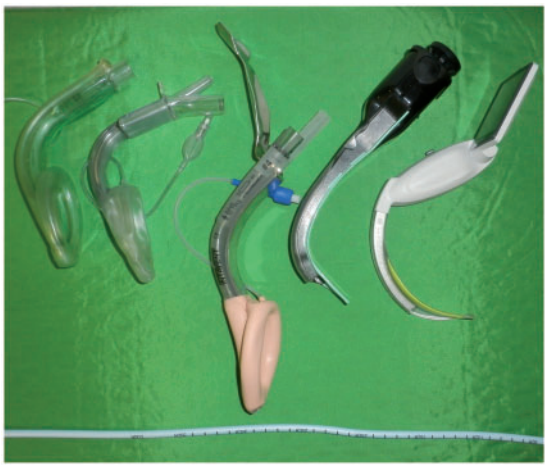

Fig 3 Airway devices described in the past 25 yr. From left to right (top row): Ambu AuraGain, LMA Supreme, Proseal LMA mounted on introducer tool, Airtraq, and McGrath MAC with X-blade. An Aintree (intubation) catheter is placed beneath them.

to the cricoid ring, providing an anatomical explanation for the occlusion he saw in his cadaveric experiments and in his series of 26 patients. However, a retrospective review of CT scans of healthy patients showed this not to be true; in 50% of subjects the oesophagus sits posterolateral to the cricoid ring, mainly on the left side.[91] Oesophageal position was also investigated using MRI imaging with and without cricoid pressure in 22 awake patients. It showed similar findings of posterolateral positioning of the oesophagus, mainly on the left side with an increase in the lateral displacement of the oesophagus from 53% to 91% with cricoid pressure.[92] Ultrasound examination to assess the degree to which cricoid pressure compressed the oesophagus showed no reduction in the anteroposterior diameter of the oesophagus. However, a novel pressure site (paralaryngeal) did achieve the desired compression of the oesophagus.[93] Our traditional understanding of the anatomical position of the oesophagus may be incomplete and 'occlusion of the upper oesophagus by backwards pressure on the cricoid ring against the bodies of the cervical vertebrae'[90] may be suboptimal or mistaken.

Further MRI studies on awake volunteers found the hypopharynx not the oesophagus lay behind the cricoid ring and it was the hypopharynx not the oesophagus that was compressed by cricoid pressure.[94] With cricoid pressure, the mean anterioposterior diameter of the hypopharynx was reduced by 35% (3.2 mm) which was thought to represent complete occlusion of the lumen.[94] This compression was maintained even when the cricoid ring was lateral to the vertebral body whilst the distal hypopharynx, the portion of the alimentary canal at the cricoid level, was fixed with respect to the cricoid ring by a complex network of muscular and ligamentous structures minimizing its mobility.[94]

The significance of these findings is: (i) compression and obliteration of the lumen may be at the level of the hypopharynx and not at the level of the oesophagus, (ii) appropriate cricoid pressure compresses the post-cricoid hypopharynx, (iii) it may not be necessary to fix the cricoid ring against a cervical vertebra to occlude the hypopharyngeal lumen, (iv) paralaryngeal pressure may achieve the desired compression at the oesophageal level, and (v) inappropriate cricoid pressure (paralaryngeal) may achieve effective oesophageal compression.[95]

Does cricoid pressure reduce the risk of regurgitation and aspiration?

In Mendelson's 1946 paper describing obstetric patients undergoing face mask ventilation with ether and nitrous oxide, the incidence of aspiration was 1:667, with a mortality rate of 1:22,000.[96] Subsequent studies during general anaesthesia suggest an incidence of pulmonary aspiration that ranged between 1:2000[97] and 1:3000[98] increasing to 1:900 during emergency surgery.[99] The mortality associated with this incidence of aspiration was between 1:45,000 and 1:70,000.[98–100] More recent studies show an incidence of aspiration of 1 in 7000 for elective patients and a mortality at 1:1,000,000.[101] The 4th National Audit Project,[88] described in total 42 cases of aspiration in 2,872,600 general anaesthetics of which there were 36 cases of aspiration of gastric contents. Twenty-nine of these 36 patients required ICU admission and half required a prolonged stay.[88] There were eight deaths as a result of aspiration of gastric contents accounting for the single most common cause of death in anaesthesia events.[88]

NAP4 highlighted that protection from regurgitation and aspiration of gastric contents was still an important issue for all anaesthetists, with the majority of aspiration events occurring during maintenance (inappropriate supraglottic airway device use) or extubation compared with before or during induction. However, NAP4 still identified several cases where there was omission of a rapid sequence induction with cricoid pressure despite strong indications for its use, followed by patient harm or death from aspiration. There were no cases where cricoid pressure was reported to lead to major complications. NAP4 concluded rapid sequence induction with cricoid force did not provide 100% protection against regurgitation and aspiration of gastric contents, but remained the standard for those patients at risk.[88]

Is cricoid pressure performed optimally and is it harmless?

Although Sellick originally described 'cricoid pressure' with firm pressure being applied once consciousness was lost, our current understanding of a force that is applied may mean that cricoid force is a more accurate term. Most problems with cricoid force occur when too much force is applied,[102] but knowledge around how much force to apply, when to apply it, and its application is inconsistent.[103–106]

Cricoid pressure is uncomfortable in the awake patient,[103] particularly when the force is greater than 20 N (2 kg) causing retching,[107] and leading to pulmonary aspiration[108] or oesophageal rupture.[109 110] Current guidelines recommend a 10 N (1 kg) force initially to the awake patient increasing to 30 N (3 kg) after loss of consciousness.[21 87 101 109] The application of cricoid pressure may also influence the lower oesophageal sphincter causing relaxation and an increased potential for vomiting, regurgitation and aspiration.[110–113]

If active vomiting occurs when cricoid pressure is applied, cricoid pressure should be removed immediately. The very problem we set out to prevent may actually be triggered by our actions.[95]

Cricoid pressure can affect:

i. Facemask ventilation - increasing inspiratory pressures, reducing tidal volumes, and may even cause complete airway obstruction.[114–119]
ii. Direct laryngoscopy - causing distortion of laryngeal structures.[120] Failed intubation is almost eight times as frequent in patients having a rapid sequence induction.[88]
iii. Laryngeal mask airway placement - impeding successful placement and ventilation.[121 122]

During the last 25 yr the practical application of cricoid pressure/force has been discussed[123–128] and challenged.[129–132] In the UK it remains a standard component of a rapid sequence induction and intubation. Cricoid pressure may reduce gastric distension during mask ventilation (the purpose for which it was originally described),[89] increasing the time to desaturation in those at risk with poor respiratory reserve, sepsis, or high metabolic requirements and providing an early indication of the ease of ventilation.[21] The force used can be reduced to 20 N (2 kg) if the patient is in a head-up position.[125]

The role of cricoid pressure has evolved from a procedure that was never or rarely released when difficulties were encountered to a pragmatic approach recognizing cricoid pressure can affect all aspects of airway management. It should be released immediately when airway difficulty (laryngoscopy, face mask ventilation or laryngeal mask airway placement) is encountered.[21 87 95] If cricoid pressure is removed, this should be done under direct vision with suction available and the assistant ready to reapply cricoid pressure in the event of regurgitation or aspiration.

Preoxygenation and increasing safe apnoea time

From the 1940's onwards preoxygenation has been recognised as an important technique before the induction of general anaesthesia to delay the onset of hypoxia, allowing more time for laryngoscopy, tracheal intubation and airway rescue.[132–137] In the 1960 s preoxygenation was emphasised with the introduction of cricoid pressure and in the 1970 s became essential as part of the rapid sequence induction and intubation technique.[90] As the development of a 'can't intubate can't oxygenate' situation is unpredictable, national guidelines have recommended preoxygenation as *desirable* in all patients.[138] The DAS 2015 guidelines for management of unanticipated difficult intubation in adults recommend '*All* patients should be preoxygenated before the induction of general anaesthesia'.[21 87]

Optimising the oxygen reservoir before induction of anaesthesia

Over the last 25 yr the optimum technique for facemask preoxygenation has been investigated. These studies describe techniques of administering oxygen to optimise the oxygen reservoir ***before*** the induction of anaesthesia and include; (i) tidal volume breathing, (ii) single tidal capacity breathing, (iii) one vital capacity breath followed by tidal volume breathing, (iv) four deep (inspiratory capacity) breaths, (v) eight deep (inspiratory capacity) breaths, and (vi) extended deep breathing (12–16 inspiratory capacity breaths).[139] Other techniques to increase the oxygen reservoir ***before*** the induction of anaesthesia include: (i) continuous positive airway pressure (CPAP),[140–143] (ii) noninvasive bilevel positive airway pressure[143] and (iii) head up positioning.[21 144–146]

Prolongation of apnoea time after induction of anaesthesia

Methods to prolong the apnoea time ***after*** the induction of anaesthesia and administration of neuromuscular blocking agents include; (i) pharyngeal insufflation of oxygen (3–10 litre min^{-1}),[147 148] (ii) nasal oxygen delivered at flow rates of <15 litre min^{-1} (described as nasal oxygenation during efforts to secure a tube or NO DESAT),[144 149 150] and more recently (iii) high flow humidified nasal oxygen at 30–70 litre min^{-1},[146 151–158] for which the acronym THRIVE has been used (transnasal humidified rapid insufflation ventilatory exchange).

Unlike regular breathing where oxygen removal from and carbon dioxide (CO_2) delivery to the alveoli are predictable using the respiratory quotient, during apnoeic oxygenation significantly more CO_2 (90%) is buffered in the bloodstream and tissues, meaning only approximately 20 ml min^{-1} is delivered to the alveoli during apnoea.[144 159 160] The subsequent reduction in lung volume generates a pressure gradient between the upper airway and the alveoli, which results in mass movement of oxygen down the trachea into the alveoli replenishing oxygen stores and increasing the safe apnoea time. The safe time is limited by a significant increase in the alveolar CO_2 concentration leading to progressive respiratory acidosis.

1. *Pharyngeal insufflation* . Pharyngeal insufflation of oxygen involves the administration of oxygen at 3–10 litres min^{-1} via a nasal catheter placed through the nose into the oropharynx or an oral tube placed through the mouth directly into the oropharynx. Oxygen insufflated at 3 litre min^{-1} through an 8 Fr catheter inserted through the nose and emerging in the oropharynx of apnoeic patients undergoing elective surgery, sustained peripheral oxygen saturations >97% throughout a 10 min study period, whilst those who did not receive pharyngeal oxygenation desaturated.[147] The authors concluded pharyngeal oxygenation provided 10 min of 'safe' apnoea time in ASA I or II patients with unobstructed airways.[147]

2. *Nasal oxygenation during intubation (<15 litre min^{-1})*. This simple technique, first described by Levitan as NO DESAT in 2010,[149] involves the application of simple nasal cannulae on the patient under a face mask during preoxygenation. After induction of anaesthesia the nasal cannula flow rate is increased to a maximum of 15 litre min^{-1}, whilst airway patency is maintained by either a jaw thrust or direct laryngoscopy. At this flow rate nearly 100% FiO_2 is achieved and the apnoea time increased. The simplicity of the technique, the universal availability of equipment and minimal change to existing practice suggest it should be used more widely to increase the apnoea time in those at risk.[144 149]

3. *Humidified high flow nasal oxygen (30–70 litre min^{-1})*. The term THRIVE was coined in 2015 by Patel and Nouraei to describe the application of high-flow (30–70 litre min^{-1}) warmed humidified oxygen (Fig. 4) in adult patients with difficult airways.[146] The high flow rates associated with this technique are only tolerated because the oxygen administered is warmed and humidified. In contrast, cold dry oxygen at high flow rates leads to mucosal drying, pain, discomfort, sinus headaches and bleeding from the nasal mucosa limiting cold dry oxygen to 10–15 litre min^{-1} in the awake patient. 'THRIVE' significantly extends the apnoea time but unlike traditional apnoeic oxygenation techniques it also improves the clearance of CO_2, preventing the increase seen in traditional apnoeic oxygenation techniques. The clearance of CO_2[146] has been replicated in clinical trials by Gustafsson[158] and To.[156] The mechanism of CO_2 clearance during high oxygen flow rates has recently been investigated and is thought to be mediated by the interaction between supraglottic

Fig 4 A humidified high flow nasal oxygen circuit by kind permission of Fisher and Paykel.

flow vortices generated by the high nasal flow and cardiopneumatic movements.

Patel and Nouraei[146] concluded that warmed humidified high flow oxygen has the potential to transform the practice of anaesthesia by maintaining oxygen saturations after commencement of apnoea to levels that change the nature of securing a definitive airway in emergency and difficult intubations from a hurried stop-start, potentially traumatic undertaking, to a smooth event undertaken within an extended safe apnoeic window.

When investigated in a randomized controlled trial of rapid sequence induction of anaesthesia during emergency surgery, high flow nasal oxygen at 30–70 litre min^{-1} was shown to be a feasible and safe method for oxygenating patients. The high flow group had a significantly longer apnoea time when compared with face mask preoxygenation, whilst an equivalent blood gas profile was maintained between the groups.[48 155] This is a powerful demonstration of the benefits of high flow oxygenation, but the increased length of time to tracheal intubation must be considered with care in the 'rapid-sequence' setting.

A randomized controlled trial in healthy children demonstrated that children allocated to receive humidified high flow oxygen maintained oxygen saturation at least twice as long as expected. Humidified high flow oxygen was effective in delaying hypoxia during apnoea, prolonging the safe apnoea time in infants and children.[153] The accompanying editorial concluded that as a new technique THRIVE had not been fully characterised in children, but held great promise and may represent a transformative technique for the safe management of difficult airways.[154]

Over the last 25 yr improvements to preoxygenation techniques in different clinical situations have identified head up positioning, continuous positive airway pressure, positive end-expiratory pressure, bilevel positive airway pressure and apnoeic oxygenation techniques to optimise the oxygen reservoir *before* induction of anaesthesia and prolong the apnoea time *after* the induction of anaesthesia.

Conclusions

The NAP4 reported that anaesthetists are almost defined by their ability to manage the airway. However, this is not a simple task answered by a simple clinical trial, as it involves the interaction between the patient and their (patho-)physiology, any airway management equipment used and its efficacy, and the skill of the operator. As we seek to make airway management safer in the next 25 yr, looking at these factors in isolation may prove overly simplistic. An ability to effectively stratify patients between low and high risk and then an ability to deal with those patients identified as difficult, presumes that any such stratification or device or innovation to manage difficulty is one hundred percent effective, which it cannot be. Regardless of the clinical and scientific discoveries of the present[146] and the future,[161 162] anaesthetists must continue to make an airway management plan for every patient that includes a second plan should their primary plan fail. Together with their team they must be trained in its expert delivery.

Authors' contributions

Manuscript preparation: all authors
Writing paper: all authors
Revising paper: all authors

Declaration of interest

A.F.M. has been loaned a variety of equipment by Amby and Aircraft (Medtronic) for evaluation purposes in the past 5 years. A.F.M. has also been loaned equipment by Accutronic, Aircraft Medical, AMBU, Cook, Fannin, Freelance, Medtronic, Storz, and Teleflex Medical for use in Airway Workshops. He has been loaned equipment for clinical use by Fisher and Paykel, who have also funded travel costs for a THRIVE development day in 2015. In 2017 A.F.M. acted as an expert advisor to the MHRA and received conference funding from MSD. A.F.M. is the RCoA and DAS Airway Leads Advisor. A.P. has received travel, accommodation and consultancy support from F&P Healthcare and is the current president of the Difficult Airway Society.

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