The Vortex Approach: Management of the Unanticipated Difficult Airway

By Nicholas Chrimes & Peter Fritz

Smashwords Edition

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Comments by Senior Critical Care Physicians on the Vortex Approach

I see the Vortex model as an advance on the current unidirectional algorithms advocated for difficult airway management – Dr Mark Adams: Director of Anaesthesia, Monash Medical Centre

The Vortex describes the way I already think about difficult airway management but articulates it in a way that can be easily communicated to others – Dr Craig Walker: Director of Intensive Care, Monash Medical Centre

The Vortex is a simple way to ensure that when bad things could happen in a critical situation, the operator is given permission to return to the last safest step, reassess and 'take their own pulse' – Professor George Braitberg: Professor of Emergency Medicine, Southern Clinical School, Monash University; Director of Emergency Medicine, Southern Health

The Vortex approach describes the difficult airway as we teach it - carefully forward with a planned escape route – Dr John Monagle: Director of Anaesthesia, Southern Health; (Acting) Medical Director Critical Care Program, Southern Health

Contents

Terminology

One of the challenges in discussing difficult airway management is that the precise meaning of even commonly used terms such as ‘apnoea’, ‘ventilation’, ‘oxygenation’, ‘surgical airway’ and even “difficult airway” itself, are subject to varying interpretation by different clinicians. The intended definitions of the key terms, as they are used in the following text, are listed in the glossary at the end of the text.

Introduction

In emergency situations, established clinical protocols are intended to help avoid fixation, facilitate teamwork and help ensure that time critical management options are not delayed or overlooked. Observations in both clinical & simulated settings, however, demonstrate that adherence to a guideline or protocol may be compromised in situations that are stressful and time pressured. This demonstrates the need for emergency guidelines to be as simple as possible so that they can be recalled and implemented effectively in a crisis situation. It is also crucial that knowledge of the appropriate protocol is shared by all members of the team, to enable them to anticipate treatment priorities or to prompt the group if the performance of an individual becomes compromised [1]. The Advanced Cardiac Life Support (ACLS) guidelines for management of cardiac arrest [2] are probably the best known example of this, and have adopted the principle of creating a simple standardised protocol, applicable to all cardiac arrest situations and teaching it universally to all staff expected to be involved in this aspect of patient care.

Developing emergency guidelines for difficult airway management presents some unique challenges. Unlike cardiac arrest, the options for management of the difficult airway are numerous and the most appropriate approach significantly influenced by the clinical context. Difficult airway guidelines therefore need not only to be simple but also robust enough to provide appropriate guidance in a wide variety of clinical circumstances.

Although advances have been made to simplify them, current difficult airway algorithms remain relatively complex [3][4]. They also typically assume that the primary intention of the airway operator is to intubate which, with the widespread use of the laryngeal mask airway (LMA), is often not the case in elective situations [5]. This can potentiate a situation where the protocol directs the airway operator to attempt interventions that may already be known to have failed by the time intubation is attempted as a rescue measure.

Historically, difficult airway algorithms have been primarily developed for the use of anaesthetists and have been taught almost exclusively to medical staff. This has lead to the development of algorithms with an anaesthetic emphasis as evidenced by phrases such as “induction of general anaesthesia” and “postpone surgery” which remain ingrained in their terminology [2][4]. Difficult airway management, especially in emergency settings, may be undertaken by anaesthetists and other critical care clinicians in environments such as hospital wards, the emergency department (ED), intensive care unit (ICU), or even external to the hospital in patient retrieval settings. These are often particularly challenging environments for airway management in which clinicians from different critical care disciplines may need to work together. Several recent reviews have demonstrated that the likelihood of serious morbidity or mortality from a major airway event is much greater in an ED or ICU than in an anaesthetic setting [5]. This makes it especially crucial that paramedical, nursing and medical staff from different critical care backgrounds have a shared mental model for difficult airway management in order to promote effective teamwork behaviours during a crisis. The anaesthetic & medical focus of existing algorithms limits their application to the broader healthcare team, reducing their utility.

What is required is a model for difficult airway management that better employs principles long associated with teaching the management of cardiac arrest. The aim should be a universal approach that can consistently be taught to staff of all disciplines involved in airway management. This should be supported by a "high stakes cognitive tool" – that is, a single tool applicable to any airway crisis, which can be readily utilised in a stressful situation by all members of the team.

The Vortex approach described in this text utilises a straightforward cognitive aid, rather than progression through a linear algorithm, to encourage a structured approach to the difficult airway. It was conceived in 2008 by Nicholas Chrimes, an anaesthetist and developed in consultation with experienced medical & nursing staff from anaesthetic, intensive care and emergency medicine backgrounds. Since then, it has been taught to medical & nursing staff working in anaesthetics, emergency medicine & intensive care as well as to paramedical staff. It is an established component of regular training sessions in difficult airway management run at Monash Simulation, the Australian & New Zealand College of Anaesthetists and Adult Retrieval Victoria and now forms an integral part of the curriculum for teaching airway management to all critical care staff across Southern Health, the largest healthcare network in Melbourne, Australia. The feedback from recipients of this teaching has been overwhelmingly positive. They report that the Vortex both heightens their awareness of priorities during difficult airway management as well as improving their ability to work through & implement the appropriate interventions in real time, in both simulated and clinical settings [6].

The aim of this text is to explain the rationale and key concepts behind the Vortex approach. It is not intended to be a teaching manual to educate staff on use of the Vortex.

Goals of Airway Management

The primary goal of airway management is ensuring alveolar oxygen delivery (AOD) is maintained. Achieving this requires both a patent airway and a mechanism for delivering oxygen to the alveoli.

• Patency can be achieved either non-surgically or surgically.
• There are three possible mechanisms to deliver oxygen to the alveoli via the patent airway:

1. Ventilation
2. Insufflation
3. Apneoic Mass Movement

The critical care physician may also consider the following secondary goals when selecting the appropriate technique for airway management:

• Airway Protection
• Airway Security
• CO_2 elimination
• Regulation of airway pressure during different phases of the respiratory cycle
• Control of timing of phases of the respiratory cycle

Whilst important, these goals are secondary to AOD because they become inconsequential if this primary goal cannot be achieved.

A healthy, conscious patient is able to achieve all of these goals independently. In the unconscious patient they become the responsibility of the critical care clinician.

There are three common non-surgical techniques by which critical care clinicians attempt to establish/maintain a patent airway:

1. Face Mask (FM) – extraglottic non-surgical airway
2. Laryngeal Mask Airway (LMA) – supraglottic non-surgical airway
3. Endotracheal Tube (ETT) – transglottic non-surgical airway

Surgical (infraglottic) methods to achieve airway patency can be usefully categorised as:

• Emergency Surgical Airway (ESA): needle or scalpel cricothyroidotomy/tracheostomy
• Definitive Surgical Airway (DSA): percutaneous or surgical cricothyroidotomy/tracheostomy

The critical care clinician's primary airway plan usually involves establishing a definitive airway which satisfies both the primary & secondary airway management goals necessitated by the clinical circumstances. When a difficult airway is not anticipated, and in many cases when it is, the initial plan is usually to attempt to achieve these goals by means of a non-surgical airway (NSA).

When successful, all three of the above non-surgical methods for airway management are equally able to fulfill the primary goal of AOD. They differ, however, in their ability to achieve the secondary goals in different clinical situations. This in turn influences the decision of which of the NSA techniques constitutes an appropriate definitive airway in a particular clinical context.

The critical care clinician thus approaches airway management having already made a decision about the preferred choice of NSA to achieve airway patency in the specific clinical circumstances. Some factors influencing this decision are disproportionately represented in certain clinical settings, resulting in different airway devices being more likely to be part of the primary airway plan in those contexts. Thus in the ED or ICU, establishing a definitive airway usually involves RSI and insertion of a cuffed ETT as the primary plan. In the setting of elective surgery, however, insertion of an LMA is a common primary airway plan and provides a satisfactory definitive airway for many procedures on patients who are not at risk of aspiration. For some short procedures, such as direct cardioversion, a FM may be the favoured form of airway management and constitute an appropriate definitive airway for this procedure.

The Unanticipated Difficult Airway

The transition from the patient maintaining their own airway to the critical care physician using one of the above non-surgical techniques to support the airway, typically involves a decrease in the patient's conscious state. This is associated with the potential for airway obstruction &/or apnoea to occur.

Techniques which allow airway management without the occurence of apnoea/airway obstruction occurring do exist, but may not always be successful or clinically appropriate. Additionally they are usually only implemented when a difficult airway is *anticipated.* As such they have limited utility in the management of the unanticipated difficult airway. Thus the risk of an interruption to oxygen delivery occurring due to depressed conscious state remains integrally involved with the process of airway management in both the elective & emergency situation.

In a routine situation achieving airway patency ultimately involves implementation of the intended definitive airway technique. When establishing a definitive airway becomes difficult, however, the goals of airway management must shift. *Factors such as prevention of aspiration & removal of* CO_2 *may have to be compromised, to achieve the primary goal of AOD*. This may require use of devices to achieve airway patency, other than the selected definitive airway and mechanisms of oxygen delivery other than ventilation.

It makes sense that when a functionally difficult airway (FDA) is encountered, the highest likelihood of success in delivering oxygen to the alveoli will result from initial reliance on techniques with which the critical care clinician is most familiar, that is ventilation with oxygen via any of the three non-surgical techniques. If a patent airway cannot be established following optimal attempts at each of these 3 non-surgical methods and the patient is not yet showing signs of spontaneous recovery of airway & breathing, immediate preparation for progression to an ESA is indicated, regardless of the patient's oxygen saturation level (SaO_2).

Thus **the trigger for performing an emergency surgical airway is the inability to establish a patent airway following optimal attempts via each of the 3 non-surgical airways**, NOT the occurrence of oxygen desaturation. Following pre-oxygenation, oxygen saturations may be maintained for a significant period despite an interruption to AOD. The time available until desaturation begins in a patient is only known retrospectively, but once it occurs, progression to critical desaturation can follow rapidly. This exposes the patient to the risk of morbidity or mortality from tissue hypoxia and may not allow adequate time for progression to an ESA. The onset of desaturation thus occurs too late to be a useful trigger for determining when to progress to an ESA (although a decline in oxygen saturation is certainly relevant to determining the urgency with which progress through optimal attempts at various airway management techniques must occur).

If the SaO_2 measurement is still 100% when optimal attempts at all 3 non-surgical methods have failed, this should be viewed as advantageous rather than as a deterrent to performing an ESA. Recognising that an ESA is required before the oxygen saturations begin to fall provides more time for the ESA to be performed. This extra time reduces the likelihood that the patient will be exposed to critical hypoxia in the meantime and provides some reduction in stress for the person performing the ESA, which potentially improves their likelihood of success.

It is also important to note that where sufficient staff are available, the final aspects of optimising attempts at achieving a NSA can occur in parallel with preparation for ESA - the two do not necessarily need to occur in series. This is a particularly important principle where oxygen saturations have already begun to decline and there is limited time remaining before the patient is exposed to critical levels of hypoxia.

Once an ESA has been performed to establish airway patency, oxygen can be insufflated to achieve AOD and optimise SaO_2, thus preventing the patient progressing to the point of critical oxygen desaturation with its attendant risks of morbidity & mortality. This provides the opportunity to mobilise resources and assess options before moving forward to establish a definitive airway by either waking the patient or converting to a definitive surgical or non-surgical airway.

Difficult airway management thus involves a simple four step sequence (Fig 1).

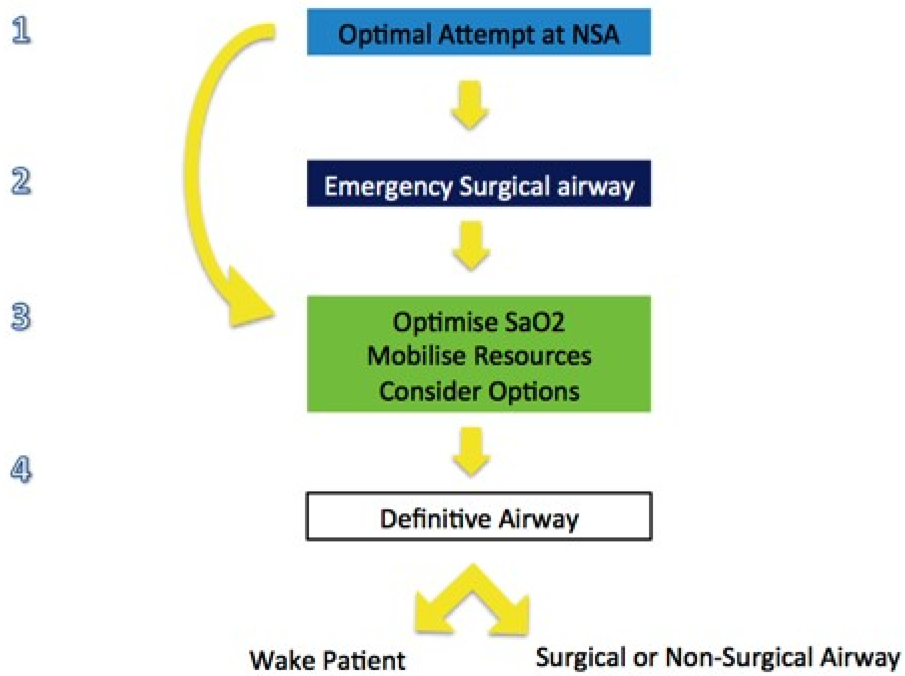

Fig 1: Four Step Sequence of Difficult Airway Management

Implementation of these four steps in the clinical setting is not always straightforward, however. Observation of simulated difficult airway scenarios and review of actual case reports have identified the following common problems with difficult airway management [5][7][8]:

- Failure to make optimal attempts at each of the 3 non-surgical airways
- Excessive airway manipulation leading to loss of ability to achieve AOD
- Failure to initiate ESA in time (or at all)
- Technical difficulties with ESA: inexperience, inappropriate technique, difficulty accessing equipment

In short, the common problems with management of the FDA stem from simple omissions of basic management steps.

The Vortex model provides a structured approach which aims to address the first three of the above points, thereby minimising the need to perform an ESA yet facilitating early progression to ESA when it is required. It centres around use of a cognitive aid which is universally applicable despite the fact that the initial technique for establishing a definitive airway may vary in different clinical circumstances. This cognitive aid is also simple enough to be visualised during a crisis, when it may be more challenging to recall more complex algorithms.

Overview of the Vortex Approach

The Vortex model uses the following simple cognitive aid to prompt team members during emergency difficult airway management (Fig 2).

Fig 2: The Vortex Cognitive Aid

To understand the use of this cognitive aid it is best to consider its components in a stepwise fashion as described below. A PowerPoint presentation outlining the Vortex is also available by clicking HERE.

The Vortex model conceptualises airway management as a funnel (Fig 3)

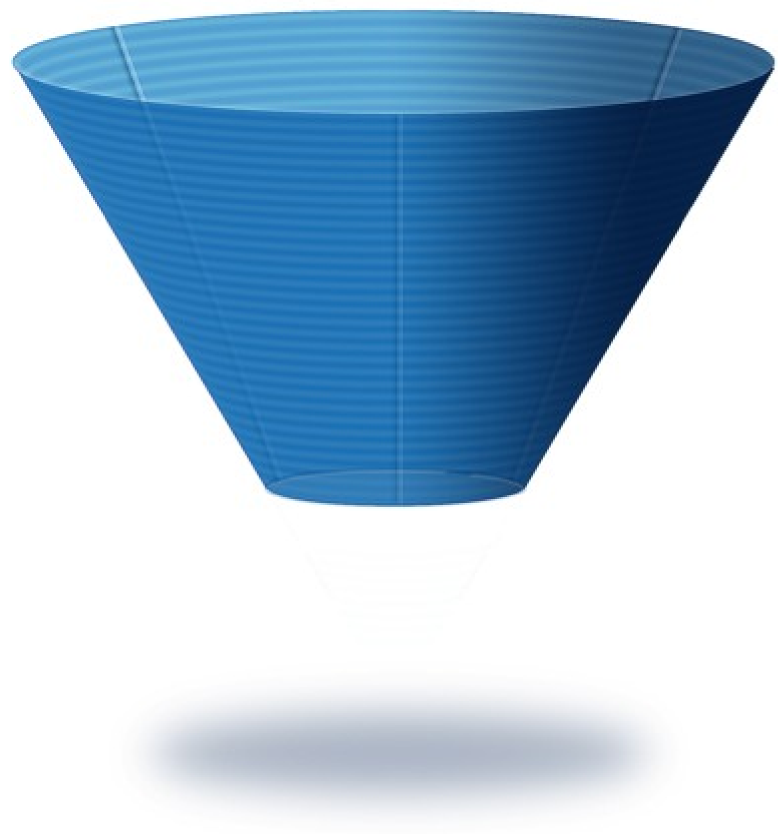

Fig 3: The Vortex (Lateral View)

Viewed from above, the Vortex funnel is divided into 3 segments, each representing one of the three NSA techniques commonly used to establish a patent airway (Fig 4).

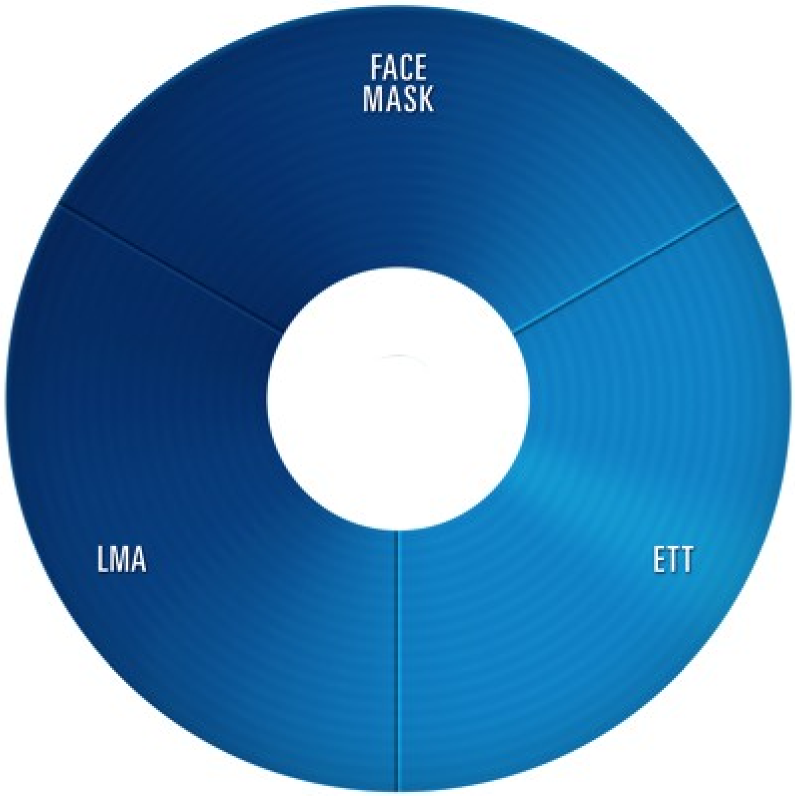

Fig 4: The Vortex (Overhead View)

As discussed above, if a patent airway cannot be achieved following an optimal attempt at each NSA technique, an ESA is indicated (Fig 5).

Fig 5: Vortex Including Emergency Surgical Airway

Use of the Vortex

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The Vortex model prompts the team to make an "optimal attempt" to achieve airway patency via each of the three NSA techniques. Whilst desirable, it may not be possible to have an "optimal attempt" at each NSA technique on the first try, as additional factors which could improve the chances of success may only be able to be identified after initial airway manipulations have taken place. Therefore when using the Vortex approach, up to three individual tries to achieve a patent airway may be had using each non-surgical technique before an "optimal attempt" with that NSA is said to have taken place (i.e. "optimal attempt" = up to 3 tries with that NSA technique). Failure to establish a patent airway by an "optimal attempt" at any of the NSA techniques leads one to spiral forward to the next until all three NSA techniques have been optimally attempted, after which a surgical airway is mandated if airway patency has still not been achieved. Any NSA technique may be used as a starting point and the remaining two techniques may be attempted in any sequence as dictated by the judgement of the airway operator in a given clinical situation. Thus taking a standard rapid sequence induction (RSI) as an example (Fig 6):

- The primary airway plan would be to insert an ETT as the definitive airway. An optimal attempt (consisting of up to three tries) is made at this initially.
- If an ETT cannot be inserted following an optimal attempt at intubation, an optimal attempt to establish a patent airway using a FM (again consisting of up to three tries) might be undertaken next.
- If this was also unsuccessful an optimal attempt at establishing an airway via an LMA must be had.
- If optimal attempts at all 3 methods to establish a patent airway via NSA techniques fail, an ESA is indicated, regardless of the oxygen saturation.

Fig 6: Use of the Vortex during failed RSI

In a different clinical situation:

- Following failure of an optimal attempt at intubation it might be the preference of the airway operator performing the RSI to attempt to establish a patent airway via an LMA (instead of moving next to a FM).
- If an optimal attempt to establish a patent airway with an LMA fails though, then an optimal attempt to establish an airway using a FM must be made next.
- If this fails then once again an ESA is indicated (Fig 7).

Fig 7: Alternative use of the Vortex during failed RSI

Consider an elective surgical situation, when performing a non-RSI intubation on a fasted patient:

- The airway operator could begin making an optimal attempt at FM ventilation whilst the administered muscle relaxant is taking effect.
- If this is unsuccessful the next step might be to perform an optimal attempt at intubation.
- If this fails, an optimal attempt to achieve a patent airway using an LMA must be the goal.
- Failure to achieve airway patency via any NSA technique again necessitates proceeding to an ESA (Fig 8).

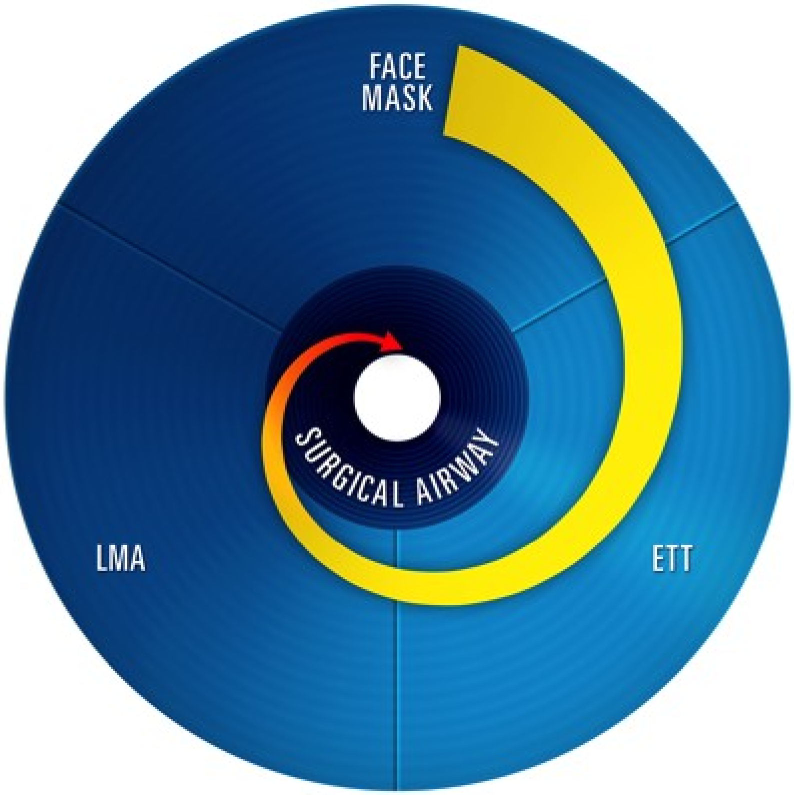

Fig 8: Use of the Vortex during non-RSI intubation

Consider yet another clinical scenario, where the planned definitive airway for a spontaneously ventilating anaesthetic in an elective surgical case is an LMA.

- An optimal attempt at LMA insertion is made initially.
- If this fails it could be followed by an optimal attempt to establish a patent airway using a FM.
- Finally if both these fail an optimal attempt at intubation is required.
- If optimal attempts at all 3 non-surgical techniques fail then an ESA is once again required (Fig 9).

Fig 9: Use of the Vortex in a planned spontaneously ventilating anaesthetic

Failure to establish a patent airway following an optimal attempt at any of the NSA techniques leads the airway operator to spiral further into the Vortex. Conversely, if any of the attempts to achieve airway patency via a NSA are successful then one instead moves outwards into the "green zone" (Fig 10).

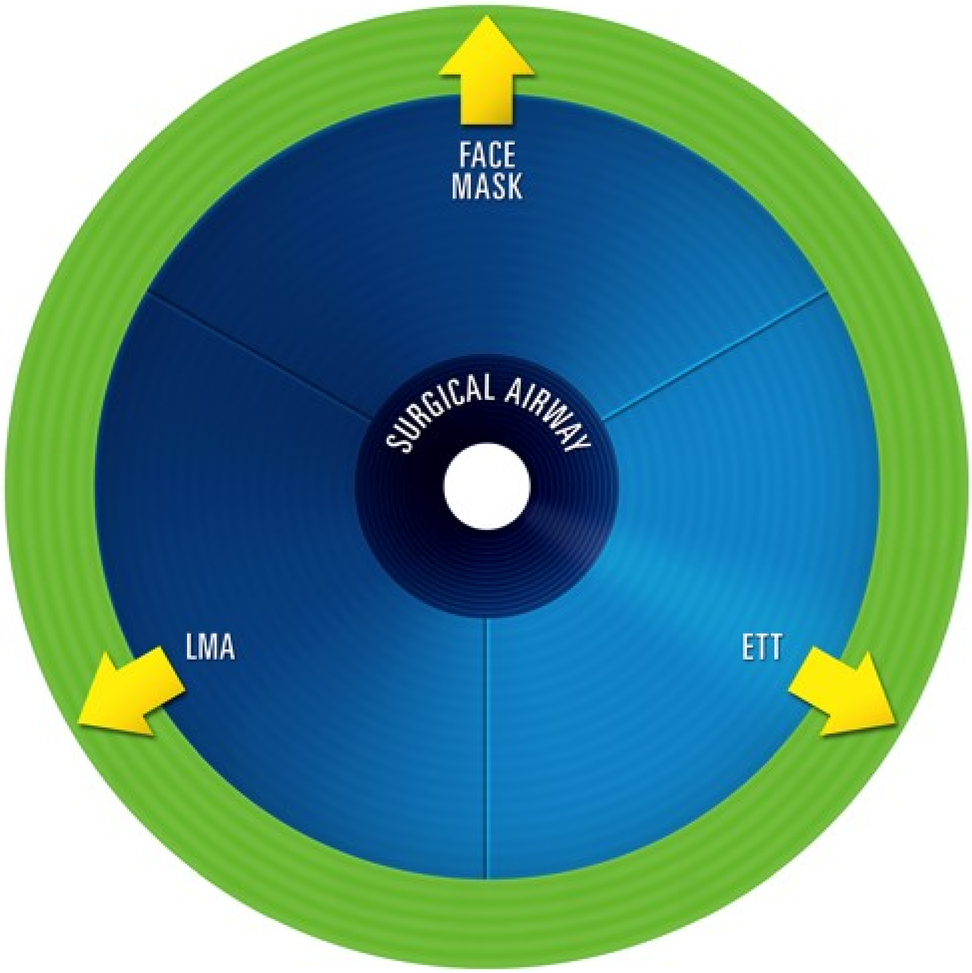

Fig 10: The "Green Zone"

In the "green zone", the airway is patent and there is confirmation that AOD is being achieved. Patients who are maintaining their own airway can also be viewed as existing in the "green zone". Thus as well as being a potential end point, the "green zone" can also represent the starting point for airway management, before the patient requires the intervention of an airway specialist to achieve airway patency. This is true even in most emergency settings where, although a reduction in SaO_2 or compromise of the patient's ability to protect their own airway may necessitate urgent airway intervention, some degree of AOD is usually still occurring. Except in the situation of acute airway obstruction or respiratory arrest, even emergency airway management begins in the "green zone".

The essential question to be answered in order to determine whether or not a patient is in the "green zone" is "Is there confirmation that AOD is occurring?". Some aspects of clinical reasoning in making this decision are discussed later in this text.

Features of the Vortex

In broad terms, the Vortex approach aims to facilitate a shared understanding amongst team members of 2 key aspects of emergency management of the FDA:

1. Firstly, the Vortex model encourages the team managing the airway to use all three NSA techniques as efficiently as possible to determine whether patency via a NSA is attainable. Should progression to an ESA be required, it can be recognised as early as possible - ideally before the SaO_2 has started to decline. The clinical significance of this is reinforced by reviews which show that basic steps to achieve a NSA are often overlooked in a crisis setting and that morbidity & mortality associated with cases in which an ESA is attempted are often not related to the performance of the procedure itself but to a delay in initiating performance of the ESA [5][7].

2. Secondly, the Vortex model emphasises to the team the significance of achieving AOD at any stage, even if this is not by the originally intended definitive airway management technique and secondary airway management goals remain that are still not being achieved. The clinical importance of this is highlighted by evidence that in many situations the inability to achieve AOD via any NSA (the "can't ventilate, can't intubate" situation) evolves from a circumstance in which AOD was previously attainable, but was lost due to excessive airway manipulation with the intention of achieving secondary airway management goals. Thus the airway operator is often the cause of the interruption to AOD via a NSA and a common cause of the requirement for an ESA [5].

The following section outlines some of the important features of the Vortex which facilitate achieving these goals.

Note that the lateral view of the Vortex below in Fig 11 is intended simply to reinforce the concepts behind the Vortex model as outlined below. The cognitive aid for clinical use is provided in the form of the overhead view in Fig 13.

The Green Zone:

The "Green Zone" is conceptualised as a horizontal surface (Fig 11) to reinforce that once AOD is confirmed there is no imperative to move immediately onwards but instead an opportunity exists to pause and strategise. The best way to proceed will then be determined by the clinical situation, the availability of equipment and the skills of the team members.

The essential point is that during difficult airway management, *once AOD is established, the patient is in a position of relative safety*. With the primary goal of airway management accomplished, *the achievement of secondary airway management goals, whilst potentially urgent, is not an emergency*. Achieving AOD, either non-surgically or via an ESA, buys time to mobilise resources (both staff & equipment), consider the available options and formulate a plan before undertaking further airway manipulations. Depending on the clinical circumstances this may involve waking the patient or making attempts to establish a surgical or non-surgical airway that is better able to fulfill the secondary goals of airway management.

Recognising that AOD has been confirmed is thus a critical point in management of the FDA, which is emphasised by the "green zone".

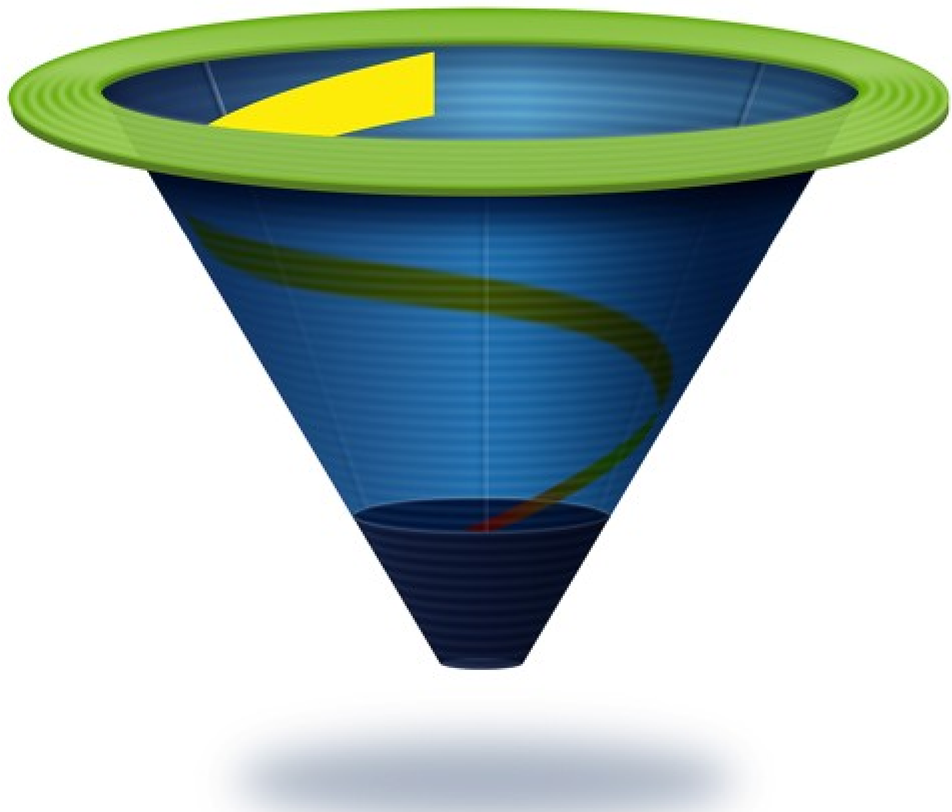

Fig 11: Lateral View of the Vortex with "Green Zone"

<u>The Funnel:</u>

The blue funnel component of the Vortex represents any point at which airway patency cannot be confirmed and there is a potential interruption to AOD. In contrast to the "green zone" this section is conceptualised as sloping in nature, to reinforce that during this phase there must be ongoing, efficient progression through each of the techniques to achieve airway patency. Until establishment of a patent airway is confirmed, the patient is not safe and there is only limited time available before the patient is exposed to critical levels of hypoxia.

The simple three segment layout of the upper portion of the funnel reinforces the need for an optimal attempt at all three non-surgical techniques to achieve a patent airway before progressing to a surgical airway. A strategy for efficiently facilitating optimal attempts at each of the techniques for non-surgical airway is discussed later in this text.

The circular nature of the funnel allows it to be non-prescriptive in terms of the sequence in which the three NSA techniques are attempted. This gives the clinician the flexibility to choose the most appropriate course of action in a specific set of circumstances, making it robust in numerous clinical contexts, irrespective of the originally intended definitive airway.

The narrowing of the funnel reinforces the diminishing time and options available as the airway operator spirals down and each non-surgical technique is exhausted.

The central placement of the surgical airway section establishes prominence of the option of ESA from the outset, serving as both a warning & reminder of its inevitability if optimal attempts at all 3 non-surgical techniques fail. This has potential value both in airway planning, as well as in the acute management of an unanticipated difficult airway. The darker blue of the surgical airway section signifies the impending cyanosis and increased risk of hypoxia induced morbidity or mortality if a surgical airway is not performed.

The overall simplicity of the Vortex model facilitates its visualisation & appropriate utilisation in the potentially stressful situation of managing a FDA. It also creates a straightforward, shared mental model for medical & nursing staff across all critical care disciplines which has the potential to improve teamwork and decision making during a crisis.

The open-ended nature of the funnel indicates that the ESA is not the final endpoint in difficult airway management but an alternative mechanism to achieve a patent airway where non-surgical techniques have failed. The ESA provides an alternate pathway back to the “green zone” where resources can be mobilised and options weighed before proceeding (Fig 12).

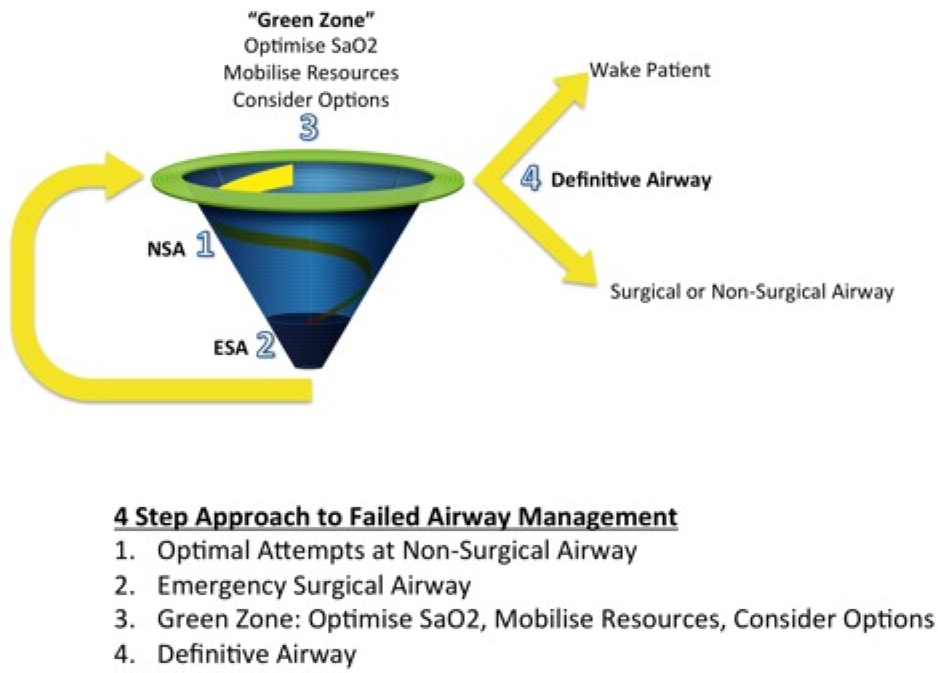

Fig 12: 4 Step Approach to Airway Management using Vortex Model

The Vortex is therefore designed to aid moving through the first three steps of the 4 step approach which was outlined at the beginning of this text.

Emergency Surgical Airway

The performance of an ESA is an unfamiliar task performed under difficult circumstances, often in patients in whom the same anatomy which predisposed to the need for the ESA, makes its performance technically difficult. These problems may be compounded by the availability of multiple techniques and devices, selection of an inappropriate technique that is aimed at providing a definitive rather than emergency surgical airway and difficulties accessing the appropriate equipment in the required timeframe. The critical care clinician & the assisting team need to be familiar with an appropriate ESA technique and be able to rapidly access the equipment to perform it. It is not the intention of this text to address the technical issues surrounding ESA. These are already dealt with extensively in other work [8].

The ESA techniques of needle & scalpel cricothyroidotomy are primarily intended to provide a patent airway as rapidly as possible in order to achieve the primary goal of AOD via insufflation of oxygen. This does not require the insertion of a cuffed airway device.

In contrast, definitive surgical airways such as percutaneous tracheostomies are typically slower to perform and intended to provide airway protection and the ability to ventilate.

As with a NSA, the priority in establishing airway patency with an ESA is to use a device that will rapidly restore AOD. Secondary goals can be deferred.

Facilitating an Optimal Attempt to Achieve Airway Patency

As described above, up to three tries geared towards further enhancing conditions so that a patent airway might be achieved, can be had at each NSA technique in the process of having an "optimal attempt". Having optimal attempts with each NSA technique requires an approach that is simultaneously efficient and rigorous to ensure that the best attempt to establish a NSA is undertaken in the least possible time. In this way the risk of exposing the patient to critical hypoxia before AOD can be restored is minimised.

To facilitate this, the Vortex approach advocates a list of optimisation strategies which can be rapidly implemented in the emergency setting of a failed airway. The individual strategies are grouped into five simple to remember categories which are applicable to all of the non-surgical techniques. These are listed on the Vortex cognitive aid (Fig 13).

1. Manipulations
2. Adjuncts
3. Size/type
4. Suction
5. Pharyngeal Muscle Tone

Within each of these categories, different strategies are listed according to their relevance to each of the NSA techniques.

<u>1. Manipulations</u>: may be undertaken at any of three levels - head & neck, larynx or device. At the first two levels the interventions are equally applicable to all three NSA techniques. At the third level, manipulations of the device are specific to the technique for NSA being attempted.

• Head & Neck: jaw thrust, sniffing position, dentures, bed height.

Jaw thrust and "sniffing position" (ear above sternal notch with ramping and face in parallel plane to ceiling) lifts the tongue away from the posterior pharyngeal wall to improve the likelihood of achieving airway patency with a FM or LMA as well as better aligning structures to facilitate a view of the larynx when intubating.

Leaving dentures in place improves the ease of establishing a patent airway with a FM whilst removing dentures facilitates getting an optimal view at laryngoscopy.

• Larynx: external laryngeal manipulation (either directly by exerting pressure on the thyroid cartilage or indirectly via easing or removing cricoid pressure) can assist with the ability to FM ventilate, the ability to correctly seat an LMA, the ability to visualise the larynx during laryngoscopy and the ability to pass an ETT into the trachea.

• Device:

FM: 2 handed approach may minimise leaks, ensure adequate cuff inflation
LMA: twist on insertion or vary cuff inflation
ETT: rotate to aid passage through larynx

2. Adjuncts: are specific to each NSA technique.
• FM: oropharyngeal and nasopharyngeal airways
• LMA: introducers/bougies/laryngoscopes/fingers may all aid correct placement of an LMA
• ETT: stylet, bougie, Magill forceps

3. Size/Type: changing the size or type of equipment used for a NSA technique may be useful but it is important that the airway operator considers whether this is likely to be of benefit in the clinical circumstances and if so limits themselves to only one alternate option for each NSA device to avoid unnecessary delays.

• FM: using a correct sized mask or a type with a better seal may decrease leaks.

• LMA: whilst certain types of LMA might allow secondary airway management goals to be addressed to some degree, these are not always the devices with which the airway operator is most familiar or adept. When airway patency has been lost, the focus must remain on the primary goal of achieving AOD and airway clinicians should be encouraged to use the type of LMA with which they are most proficient at achieving a patent airway. In particular the intubating LMA is a useful device to consider as a means of intubating the trachea when already in the “green zone”. It should not be used as a device to restore lost airway patency when operating in the “funnel” of the Vortex, however, unless the airway operator is as familiar with its use and as confident of achieving airway patency with it as they are with more commonly used types of LMA.

• ETT:

Different laryngoscope: using a different laryngoscope size or type (may involve change to handle, blade or use of video assisted device) may improve view of larynx in order to direct the ETT.

Different ETT: using different ETT size or type may aid passage of ETT into trachea

4. Suction: suctioning the airway in order to remove blood, secretions or foreign material may improve laryngoscopic view or establish patency by any NSA technique.

5. Pharyngeal Muscle Tone: residual muscle tone can impede establishment of a patent airway with a FM or LMA or impair achievement of an adequate view of the larynx when intubating. Conversely reduction of normal pharyngeal muscle tone can also be the precipitant of airway obstruction in a patient who was previously spontaneously maintaining their own airway. Safely manipulating pharyngeal muscle tone to optimise

attainment of a NSA thus requires consideration of the clinical situation. The most important initial consideration is whether or not AOD is being achieved (i.e. is the patient in the "green zone"?).

• Patient in "Green Zone": in the patient in whom AOD is confirmed it may be reasonable to consider augmenting muscle relaxation to facilitate intubation in circumstances where suboptimal relaxation is thought to be making a significant contribution to the difficulties encountered. The benefits of this must be weighed carefully against the dangers of compromising existing AOD by excessive manipulation of the airway. Perhaps the most common and important application of this strategy is in selecting an appropriate dose of muscle relaxant at the initiation of airway management (as the awake, spontaneously breathing patient is considered to be in the "green zone") and allowing sufficient time for it to take effect before instrumenting the airway.

• Patient not in "green zone": when AOD cannot be confirmed, the appropriate course of action is dependent on the prospect of spontaneous recovery of airway patency taking place before critical hypoxic injury occurs. Where there is a prospect of recovery within this time frame, the wisdom of any intervention which delays this recovery must be seriously questioned and techniques which accelerate this recovery are usually preferred. Where there is no prospect of recovery within this time frame, however, consideration should be given to enhancing pharyngeal muscle relaxation if excessive tone is thought to be contributing to the difficulty in establishing a patent NSA.

Patient not in "green zone" and prospect of spontaneous recovery: if AOD cannot be confirmed but there is a possibility of the patient recovering spontaneous maintenance of airway patency before critical hypoxic injury occurs (as may sometimes be the case during RSI), then consider reversing drugs such as neuromuscular blocking drugs, opioids & benzodiazepines to <u>increase</u> pharyngeal muscle tone and encourage spontaneous recovery of airway patency.

Patient not in "green zone" and no prospect of spontaneous recovery: if AOD cannot be confirmed and there is no prospect of patient recovering spontaneous maintenance of airway patency before critical hypoxic injury occurs (e.g. long acting neuromuscular blocker used and not readily reversible), consider administering further anaesthetic/muscle relaxant to <u>decrease</u> pharyngeal muscle tone to facilitate establishment of a NSA (only if excess muscle tone is thought to be contributing to difficulty in establishing a NSA).

When considering the above optimisation strategies for establishing a NSA, a balance must be struck between maximising opportunities for success with a non-surgical technique and the risk of unnecessarily delaying progression to the next intervention by persisting with an unsuccessful technique or traumatising the airway secondary to excessive manipulation, impairing the ability to establish a NSA. The following principles guide implementation of the above optimisation strategies to facilitate this.

Purpose: all subsequent tries at NSA must be purposeful. If another try with a particular NSA is to be had, something must have been changed from the previous try which makes success more likely. There is no value in repeating the same action and expecting a different result.

Context: the merits of each of the above 5 groups of optimisation strategies should be considered according to the specific clinical circumstances. Exhaustive implementation of every intervention listed when managing all difficult airways is not recommended. Not only will this will be time consuming but not all manoeuvres will be useful or appropriate in every situation. Assessing the value of any optimisation strategy relies on the clinical judgement of the airway operator as to whether it is likely to improve the probability of restoring airway patency and AOD in a particular instance.

Structure: the simple categorisation of the optimisation strategies allows them be rapidly "checked off" during an airway crisis, either by the primary airway operator or as prompts from other members of the team. This provides a reminder of possible strategies, which can then be implemented or discarded, to minimise the chances of an opportunity to establish a NSA being overlooked, whilst maintaining a time-efficient approach which avoids unnecessary airway manipulations.

Limits: it is suggested that having more than two tries before declaring an "optimal attempt" at any of the NSA techniques should be avoided and that there should be no more than 3 tries at any NSA technique. The overriding principle is that the number of times any NSA technique is tried should be minimised. As many as possible of the remaining optimisation strategies which are potentially of value should be implemented at the next try, with the intention of making "the next go, the last go".

Planning: consideration of the potential merits of the optimisation strategies even before administering anaesthetic agents or muscle relaxants allows as many as possible of these to be implemented before the patient is placed at risk of an interruption to AOD. This process also raises the team's awareness of any remaining strategies which might need to be subsequently implemented if the patient does have a FDA, thereby decreasing the likelihood that they will be overlooked. Consideration of the optimisation strategies during airway planning also provides the opportunity to assemble the relevant equipment & expertise so that it is available to implement in a timely fashion if an airway crisis arises. Thus while the above list of optimisation strategies is primarily designed for use during the emergency management of an unexpected FDA, it is also useful in teaching routine airway planning & preparation. It must be remembered, however, that the list of optimisation strategies utilised in the Vortex approach is not exhaustive and there are other potential optimisation strategies (e.g. shaving of a beard to improve FM ventilation) which, whilst useful during the preparation phase, are not feasible during the acute phase of managing a FDA once AOD has been interrupted. These types of strategies are therefore not part of the Vortex optimisation tool. Consideration of the Vortex optimisation strategies is thus only one aspect of airway planning & preparation and other potential interventions must also be contemplated.

In combination, the above principles allow rapid consideration of the potential optimisation strategies for each NSA technique, +/- implementation of those considered appropriate within 3 tries. This process constitutes an "optimal attempt" at the NSA technique in question. Whether or not an optimisation strategy is considered appropriate in a given context depends on the judgement of the airway operator as to whether the technique is both likely to be of benefit and able to be implemented within an appropriate time frame/number of tries.

This structured approach to optimising attempts at a NSA not only increases the likelihood of achieving airway patency, but also provides a clear endpoint to the optimisation process where these attempts are unsuccessful. This has the potential to improve situational awareness by promoting recognition by the airway management team that a particular NSA technique will not be useful in the current situation. This provides them with "permission" to move on to a different technique rather than persist with techniques that are unsuccessful, potentially reducing the incidence of a common fixation error.

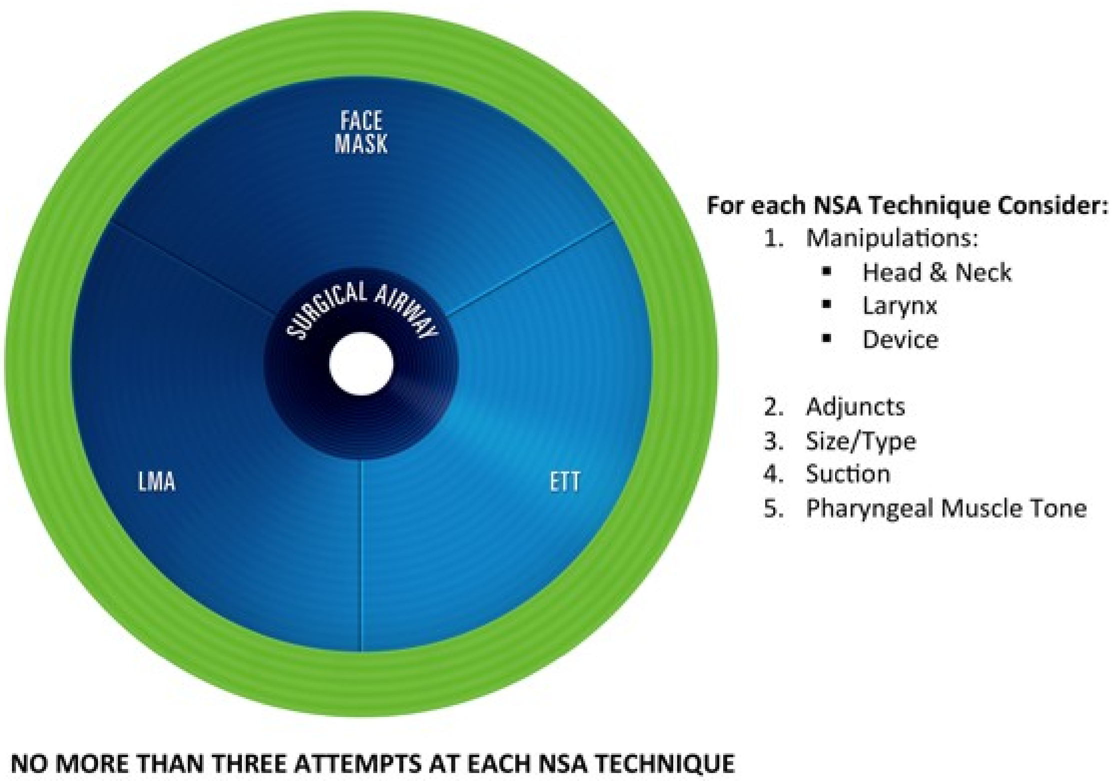

Fig 13: The Vortex Cognitive Aid with Optimisation Strategies

Assessing Airway Patency

Integral to the process of moving through the Vortex is the ability of the clinician to efficiently assess success or failure at each stage. This requires clarity about what is being assessed and the criteria that allow it to be confirmed.

There has been a recent move towards favouring use of the term "oxygenation" as the crucial issue to be achieved during difficult airway management. The ultimate importance of oxygenation from a conceptual standpoint cannot be disputed, but in terms of clinical decision making, trying to determine whether “oxygenation” is taking place presents some practical problems.

Clarity: a lack of clarity sometimes exists amongst critical care staff about whether the term “oxygenation” refers to delivery of oxygen to the alveoli, the blood or the tissues [9]. Whilst tissue oxygenation is obviously the ultimate goal in terms of patient wellbeing, factors influencing pulmonary oxygen transfer & delivery of oxygenated blood to tissues, which are unrelated to airway patency, have a significant impact on this. Clearly in terms of airway management it is alveolar oxygenation which is the important goal. The term AOD, synonymous with “alveolar oxygenation” has been used in this text to circumvent this ambiguity.

Confirmation: even with the goal of “alveolar oxygenation” clearly defined the problem remains that AOD cannot be directly measured. The presence or absence of alveolar oxygenation must be inferred from other clearly definable endpoints. As a result it is not always simple to assess whether or not AOD is taking place in a time frame appropriate for decision making in difficult airway management. When asked how they would assess that they “can’t oxygenate” a patient, critical care physicians almost invariably respond that witnessing falling oxygen saturations is the key indicator [9]. As discussed above, however, waiting for the oxygen saturations to fall before determining that AOD is not occurring potentially creates a significant delay in decision making and exposes the patient to increased risk. Blood oxygenation can be measured by a pulse oximeter but its relationship to alveolar oxygenation is inconsistent. Whilst an upward or downward trend in the oxygen saturation suggests success or failure respectively in achieving adequate AOD (albeit with a sometimes significant time lag which can complicate interpretation [10][11]), the maintenance of high oxygen saturations for a prolonged period following pre-oxygenation indicates only that oxygen had previously been delivered to the alveoli and continues to be transferred to the blood. It does not provide any information about whether AOD is currently occurring.

It is only possible to reliably infer that AOD is occurring at a given point in time in the presence of any of the following situations:

- Ventilation of the alveoli with oxygen
- Direct Tracheal Insufflation of oxygen
- SaO_2 trending upwards

The Vortex model thus advocates that the decision of whether a patent airway has been achieved is best assessed by confirming the success or failure of the mechanism of oxygen delivery being used. This will in turn relate to the technique used to establish airway patency. Where a non-surgical airway technique is being used, the mechanism of AOD is usually ventilation whilst where an ESA is employed the minimum requirement for AOD is insufflation. Confirmation of ventilation is thus used to assess patency of a NSA whilst confirmation of insufflation is used to assess patency of an ESA (it is recognised that this is a generalisation as a bougie placed translaryngeally into the trachea may allow oxygen insufflation but not ventilation whilst an ESA may allow ventilation in addition to oxygenation).

Confirming Airway Patency via a NSA

In the absence of pulmonary pathology and equipment malfunction, when airway patency is achieved by any of FM, LMA or ETT, delivery of oxygen to the alveoli by positive pressure ventilation is always possible provided an adequate seal is present. Thus provided the cuff of the NSA device creates a proper seal, inability to achieve ventilation of the alveoli by one of the three non-surgical airways reflects a lack of airway patency (breaching the cuff seal with attempts at positive pressure ventilation also frequently indicates airway obstruction more distally). As such, in addition to providing the mechanism for oxygen delivery, ability to ventilate is in fact, the primary mechanism by which critical care physicians determine whether airway patency has been achieved using a NSA. Thus **ventilation of the alveoli with oxygen is the key indicator that the primary goal of airway management has been achieved** when using one of the 3 non-surgical airways.

The criteria for assessing whether ventilation of the alveoli is occurring via a NSA are not specifically related to difficult airway management but should instead be considered part of the core skill set of any clinician charged with the responsibility of independently managing a patent airway in a routine setting. As such the Vortex approach does not specify how clinicians assess whether or not ventilation is occurring. Although it is recognised that, according to the clinical context, the combination of a number of factors may be used by the experienced clinician to determine whether ventilation is occurring, the critical role of $ETCO_2$ monitoring cannot be underestimated [5][7].

Confirming Patency via an ESA:

Insufflation of oxygen is the minimum requirement for AOD via an ESA. Whilst ventilation may be possible via an ESA it not required for AOD and need not be a goal at this stage of airway management.

Ability to insufflate via an ESA is confirmed by the ability to deliver oxygen via a conduit placed directly into the trachea without occurrence of surgical emphysema. Confirmation of tracheal placement of an ESA is best discussed in relation to the technique for ESA placement and is beyond the scope of this text.

An encouraging trend in SaO_2 measurements should be one component by which the critical care physician ultimately assesses the adequacy of either ventilation or insufflation as a mechanism to achieve AOD.

Airway Training Programs

The Vortex approach is directed at addressing the emergency management of the unanticipated FDA. Effective airway training programs for critical care physicians are crucial to minimise the chances of this situation arising in the first place. The importance of thorough airway assessment, strategic airway planning/preparation, supervision, timely seeking of assistance and technical competence must not be underestimated. The Vortex approach has a role to play in this phase of airway management also, as the cognitive tool and list of optimisation strategies can make a valuable contribution to the structured planning & preparation for airway management prior to the administration of sedating/paralysing drugs which might lead to an interruption in AOD.

This type of content expertise in airway management however, whilst a necessary prerequisite for emergency management of the FDA, does not necessarily translate into the ability to effectively implement these skills in a crisis setting. Training staff to use the Vortex model for emergency management of a FDA requires more than simply familiarising them with the cognitive aid itself. Detailed discussion of this training & its implementation is beyond the scope of this text, but the following aspects of the existing Vortex training programs are worthy of note.

Seniority: the Vortex model aims to facilitate the effective & judicious implementation of existing technical skills & clinical judgement, when an airway crisis arises. The emphasis of Vortex training is on consolidating and categorising existing knowledge in a way that makes decision making in a crisis more straightforward. Training in use of the Vortex should thus be directed at learners who have a sufficient groundwork of knowledge, skills & clinical experience, gained from general training in airway management, to inform decision making about the appropriateness of the above strategies and ensure their effective implementation.

Consistency: all clinicians receiving training in the Vortex approach require a consistent level of familiarity not only with the approach itself, but with certain key techniques and devices. Unfortunately in the absence of a standardised approach to the core elements of advanced airway training and equipment access, exposure to these often varies markedly between critical care disciplines, different departments and individual clinicians. In order to ensure that team members not only adopt the same framework for decision making, but that they are able to implement the strategies to efficiently optimise their attempts at achieving a NSA, it has been necessary to include some of this basic skill training in existing Vortex training programs.

Teamwork Training: analogous to many cardiac resuscitation training programs, following education on the tool itself and training in relevant skills, difficult airway education sessions utilising the Vortex model have been supplemented, where possible, with a series of simulation-based drills in an inter-professional setting to give clinical teams the opportunity to practice the consideration +/- implementation of these optimisation strategies in a structured manner during a crisis. These sessions include training in behavioural strategies to facilitate effective crisis management.

Universality: education sessions relating to use of the Vortex approach should be provided to all medical, nursing and paramedical staff involved in airway management so that all have a consistent approach to managing a difficult airway when this crisis arises. This is in keeping with the approach that has been adopted in the teaching of the ACLS guidelines for cardiac arrest management and, amongst medical staff, trauma management according to the Advanced Trauma Life Support (ATLS) and Emergency Management Of Severe Trauma (EMST) teaching programs.

Conclusion

The Vortex approach provides a simple framework for thinking about emergency management of the FDA. Rather than simply being a "new airway algorithm" it is comprised of a specific education program based around a simple conceptual model for decision making and reinforced by a straightforward cognitive tool. In combination these elements provide a cognitive model which is not only accessible to both medical & nursing staff across multiple critical care disciplines but is simple enough to be utilised during the stress of crisis management and is additionally able to provide a useful format for effective airway planning. The Vortex approach employs many of the principles associated with training for cardiac arrest management, including simple guidelines and universal education of all staff expected to be involved in managing the emergency.

There are, however, a number of important differences between management of the difficult airway and cardiac arrest. When managing cardiac arrest it is possible to always advocate "CPR, adrenaline and defibrillation of shockable rhythms" as the immediate management of a pulseless patient, but the best specific intervention to manage an obstructed airway is heavily influenced by clinical context as well as operator experience and preferences.

Confronted with a difficult airway the critical care clinician has a multitude of potential management options and little evidence to support the use of one particular technique over another. In addition the appropriateness of any particular technique may vary according to the clinical circumstances (hence the need for algorithms for different clinical situations in the Difficult Airway Society (DAS) [4]). Different clinicians may also have varying experience with the available techniques and even those with comparable experience often have varying degrees of success with any specific technique "in their hands" leading them to favour a particular intervention. Similarly the availability of equipment in different clinical environments is, unfortunately, variable.

Having a universally applicable set of guidelines for difficult airway management analogous to those used for cardiac arrest, and a "high stakes cognitive tool" to prompt their implementation, thus necessitates that the Vortex be *goal* rather than *technique* oriented. Thus rather than encourage the use of specific techniques or devices, the Vortex model emphasises the importance of a limited number of key goals, shared amongst the team. This goal oriented approach directs team members to efficiently make optimal attempts to obtain a NSA by each of the three commonly used techniques, and provides general strategies to achieve this, before proceeding to an ESA. In this regard the Vortex approach adopts a very different philosophy to that of the DAS guidelines, which are based around mandating specific interventions [4]. The Vortex approach takes the view that the clinician managing the airway should make the decision as to the best method to achieve these goals.

This approach is readily justifiable, firstly because the Vortex is concerned with providing a guideline for clinicians who, if they are independently managing a patient's airway, should already be experts in airway management to some degree. This is a vastly different situation from the ACLS guidelines, which are taught to a broad spectrum of clinicians, many of whom are do not have expertise in resuscitation, let alone cardiology.

As such it is quite reasonable to allow the clinician managing an airway crisis the discretion to decide what specific intervention to undertake, provided the key goals are being addressed. This approach strikes a balance between adherence to a structured guideline and acknowledgement of the expertise of the airway operator. In allowing clinicians to use their clinical judgement, the Vortex has the potential to improve adherence to the guideline as well as improve the outcome.

This approach is also consistent with what is known about why hypoxia related morbidity & mortality occur in association with management of the FDA. In addition to lack of adequate planning/preparation/expertise, adverse outcomes typically result from fundamental omissions in airway management, such as a failure to attempt one or more of the three NSA techniques &/or failure to move to a surgical airway when these fail [5] [7]. The use of specific advanced skills or pieces of equipment to achieve the goal of airway patency via each of the NSA techniques is not usually a factor. This is not to underplay the importance of familiarity with and availability of core pieces of airway equipment such as oropharyngeal airways, laryngeal masks, bougies, etc. Prompting the use of this basic equipment is incorporated into the Vortex approach and the authors strongly advocate that standardisation of airway training and availability of equipment constitute a crucial foundation to its implementation.

The Vortex provides the flexibility required to address the fluid nature of an airway crisis making it robust enough to be used effectively in a wide variety of clinical contexts. At the same time it provides enough consistent "checkpoints" that in combination with inter-professional training it has the potential to enhance teamwork.

Combined with the use of techniques to prolong the time until critical desaturation and familiarity with the techniques for performance of an ESA, the Vortex aims to minimise the risk of patients suffering morbidity or mortality due to critical hypoxic episodes occurring during difficult airway management. Although the usefulness of the Vortex in clinical practice is currently anecdotal, the majority of the established airway algorithms are not evidence based. Like the Vortex, they are based on expert opinion and sound reasoning. What the Vortex adds to these is simplicity, flexibility, contextual robustness and the inclusion of principles designed to promote teamwork behaviours in a crisis.

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Glossary

The authors recognise that in some cases the terms listed below, although commonly used, have no accepted strictly defined meaning whilst in others there may be ambiguities or technicalities which would allow legitimate alternate definitions by some clinicians. The definitions given below simply reflect the intended meaning of the respective terms as they are employed in this text. Every effort has been made to avoid creating contrived or idiosyncratic definitions and it is hoped that these definitions generally align with the meanings commonly intended in their typical clinical usage. In some cases new terms have been developed where it was felt that existing terminology was not clinically useful or sufficiently precise.

Airway Assistant: the member of the airway management team primarily responsible for assisting the airway operator through provision of equipment and prompting.

Airway Operator: the member of the airway management team responsible for performing airway interventions at a particular point in time.

Airway Patency: degree to which gas is able to pass though the airway to reach the alveoli.

Airway Protection: ability to prevent solids & liquids passing through the airway to reach the alveoli (i.e. ability to prevent aspiration).

Airway Security: the degree of confidence provided that airway patency and other secondary airway management goals will not be compromised by dislodgement/lack of stability of a given airway management technique. As a generalisation airway security is typically seen to be greater with an endotracheal tube than an LMA and with an LMA than a facemask.

Alveolar Oxygen Delivery: see alveolar oxygenation.

Apnoea: absence of both ventilation and spontaneous ventilatory effort

Apneoic Mass Movement (AMM): movement of oxygen from an oxygen source to the alveoli due to the reduction in alveolar barometric pressure created by the discrepancy between the volume of oxygen removed from, and CO_2 delivered to, the alveoli. This gas movement continues during apnoea and does depend upon either generation of a positive pressure in the upper airway or respiratory effort by the patient. The driving force for gas movement is a decrease in alveolar pressure not molecular diffusion. Unlike ventilation as a mechanism for delivery of oxygen to the alveoli, the occurrence of AOD via AMM cannot be easily confirmed in a time frame relevant to decision making regarding progression through the Vortex and the need for an ESA. Failure of adequate AOD via AMM can only be inferred retrospectively by observing a decline in the oxygen saturation of the patient. Thus although airway patency will frequently be achieved during laryngoscopy, potentially allowing AOD via AMM in a patient who has been adequately pre-oxygenated and is receiving nasopharyngeal oxygen insufflation, the inability to confirm this means that the Vortex approach must restrict itself to establishment of a NSA via techniques which allow immediate confirmation of AOD via the occurrence of ventilation (i.e. FM, LMA, ETT). AMM can, however, play a crucial role in prolonging the time to critical desaturation [12] and minimising the risk of exposing a patient to critical hypoxia whilst attempting to establish a NSA.

Critical Desaturation: oxygen saturation which is low enough to present a high risk of morbidity/mortality from hypoxia even with very short periods of exposure (> 3mins).

Definitive Airway: an airway management technique which satisfies all the goals of airway management in a particular set of circumstances such that conversion to another airway management technique is not anticipated. The definitive nature of any particular method of securing the airway is thus relative according to the context. Determination of which non-surgical airway technique is appropriate is largely dependent upon the following factors.

Airway Security: issues such as shared airway, limited access to the airway, difficult airway, etc. may lead practitioners to opt for an ETT to minimise the likelihood of the airway device becoming dislodged and patency compromised.

Aspiration Risk: issues such as fasting status, reflux or delayed gastric emptying will determine not only the need for a cuffed ETT but also for rapid sequence induction (RSI).

Mode of Ventilation: whether ventilation is to be spontaneous or via applied intermittent positive pressure.

Functionally Difficult Airway (FDA): an airway in which satisfactory implementation of the intended definitive NSA is not successful at the first try, necessitating further interventions to attempt to optimise securing a patent airway. This includes not only difficult intubation but also difficult FM ventilation and difficulty with ventilation via an LMA. The definition of FDA therefore includes any situation in which airway management is anything less than completely straightforward and has been adopted as it reflects the circumstances in which the principles of the Vortex approach are likely to be useful. This is a much broader definition than those commonly used to describe the "difficult airway". The intention is to move away from the concept of the difficult airway as being something purely anatomical, which is presented to the airway operator and instead emphasise the airway operator's contribution to the FDA. In addition to airway anatomy, factors such as context, preparation, technique and clinician experience contribute to whether an airway is functionally difficult to manage. As such a whether or not a patient has a "difficult airway" should not be considered a static situation but one that may vary between different clinicians using different techniques in different circumstances.

Non-Surgical Airway (NSA): a patent airway achieved without need for incision/puncture of the normal airway anatomy which allows for transglottic delivery of oxygen by attachment of an oxygen source at the mouth. There are three commonly used techniques to achieve a non-surgical airway:

Extraglottic: breathing of room air or delivery of inspired gas via nasal prongs or mask. In relation to difficult airway management in a critical care setting, this is most commonly a cuffed face mask attached to a bag-valve-mask device or anaesthetic circuit. Additional nasal/pharyngeal devices may be required to support this type of airway. For clarity the term "facemask" has been to refer to any extraglottic airway device in this text.

Supraglottic: delivery of inspired gas via devices which sit above the larynx. The most commonly used device is the laryngeal mask airway (LMA) but other devices such as the cuffed oropharyngeal airway (COPA) and Combitube ® exist. For clarity the term "LMA" has been used to refer to any supraglottic airway device in this text.

Transglottic: delivery of inspired gas via devices which sit are passed through the larynx into the trachea. The most commonly used device is the endotracheal tube but bougies with lumens and other jet ventilation devices also fit into this category. For clarity the term “ETT” has been used to refer to any transglottic airway device in this text.

Insufflation: blowing of gas into the lungs via a conduit placed directly into the airway. Ideally the conduit is placed directly into the trachea, either infraglotically via an emergency surgical airway or via a transglotically placed device such as a bougie with a lumen that permits oxygen insufflation.

Oxygenation: delivery of oxygen to a specified area. Typically used to refer to three distinct but related concepts depending to what destination the oxygen is being supplied:

Alveolar oxygenation: delivery of oxygen to the alveoli (= alveolar oxygen delivery). Dependent upon a patent airway and a mechanism for oxygen delivery to the alveoli. Relevant to goals of airway management. Key factor relevant to decision making in difficult airway management but cannot reliably be directly measured in clinical setting (assessing this via end-tidal oxygen concentrations presumes that the end-tidal gas is alveolar in origin, which may not be correct in the setting of compromised airway patency).

Blood oxygenation: delivery of oxygen to arterial blood. Dependent upon presence of oxygen in the alveoli (from either current or previous alveolar oxygen) and oxygen transfer across alveolar membrane into pulmonary capillaries. Directly measurable in real time by pulse oximetry. It is possible, however, for measured oxygen saturation to be high despite interruption to alveolar delivery, due to the presence of previously established alveolar oxygen stores achieved during pre-oxygenation. Conversely impaired gas transfer may produce poor measured oxygen saturation despite the presence of adequate alveolar oxygenation. Trends or persistent low values in SaO_2 may be relevant to decision making in difficult airway management but sustained high values may be misinterpreted.

Tissue oxygenation: delivery of oxygen to the tissues. Dependent upon blood oxygenation, haemoglobin concentration and cardiac output (i.e. oxygen flux). Blood flow to individual tissues determines oxygenation of specific tissue beds. Measurement requires knowledge of these three components. In routine settings this is typically inferred from knowledge of SaO_2, haemoglobin concentration and adequate blood pressure. Not a relevant concept to decision making in difficult airway management as blood oxygenation gives a more direct indication of alveolar oxygen delivery.

Surgical Airway: a patent airway achieved by infraglottic incision/puncture of the normal airway anatomy allowing for direct tracheal delivery of oxygen by attachment of an oxygen source to the anterior neck. Surgical airways can be usefully sub-categorised as follows:

• Emergency Surgical Airway (ESA): infraglottic airway which can be rapidly inserted in a time critical situation for the primary purpose of achieving alveolar oxygen delivery via direct tracheal insufflation. Whilst secondary airway management goals such as airway protection & ventilation may be achievable via some forms of ESA, this is not their primary function. An ESA is most commonly achieved via one of two techniques (whilst these are described below in terms of the cricothyroid membrane, where this is not easily identifiable they can be performed anywhere accessible below the glottis:

Needle cricothyroidotomy: introduction of a large bore cannula into the trachea through a hole created in the cricothyroid membrane using a needle. This can be done percutaneously (closed needle cricothyroidotomy) or after blunt dissection to better reveal the anatomy of the relevant cartilages (open needle cricothyroidotomy).

Scalpel cricothyroidotomy: introduction of a bougie &/or endotracheal tube into the trachea via a hole created in the cricothyroid membrane using a scalpel. More commonly referred to as a "surgical cricothyroidotomy" this terminology has been adopted to avoid confusion with the umbrella term "surgical airway" and create a consistent nomenclature which distinguishes the two ESA techniques according to the device used to pierce the cricothyroid membrane. Where an ETT is primarily inserted via scalpel cricothyroidotomy ESA & DSA are achieved simultaneously.

• Definitive Surgical Airway (DSA): infraglottic airway which typically allows for AOD by ventilation as well as providing airway protection. Assuming equal familiarity of a given operator with all techniques, these are usually slower to perform than an ESA but there may be circumstances in which someone highly skilled at DSA is able to perform this more quickly than a novice can perform an ESA. Includes percutaneous tracheostomy kits as well as other cuffed devices which can be use a Seldinger technique to convert an ESA into a DSA (e.g. Melker kit).

Ventilation (of the alveoli): cyclical inflation & deflation of the lungs to achieve exchange of gas between the alveoli and a fresh gas source. In this text the term "ventilation" has been used synonymously with "ventilation of the alveoli". The authors acknowledge that in strict physiological terms it is possible to argue that ventilation of dead space alone could also legitimately be described as "ventilation". In contrast to the term "oxygenation" in which there is a lack of clarity amongst clinicians about where oxygen is being delivered, "ventilation of the alveoli" consistently appears to be the intended meaning of the term "ventilation" in clinical practice, particularly in the context of airway management. For some degree of ventilation of the alveoli to occur, the volume of gas exchanged need only exceed the volume of the anatomical dead space. The volume of cyclical inflation/deflation does not need to be of the magnitude of a tidal volume. "Adequacy" of ventilation is a relative concept depending on the context and whether one is using the criteria of oxygen delivery, CO_2 removal or lung expansion to establish "adequacy". In the setting of failed airway management "adequacy" may reflect ventilation that is merely adequate to prevent critical desaturation.

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Comments or questions on this text are welcomed. Please feel free to email the authors.

Other Publications by these Authors

The COAT & Review Approach: How to recognise and manage unwell patients. Nicholas Chrimes and Julia Harrison. Monash Simulation, 2013

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