Emergency anterior neck oxygenation strategies in the 'Can't Intubate, Can't Oxygenate' scenario

Dr Andrew Baker Dr Adam Revill & Dr Richard Hughes. Adapted from material produced by
Dr Andrew Heard, Dr David Lacquiere & Dr Adrian Woollard

Background

Welcome to the South West Emergency Airway Training (SWEAT) course for management of the Can't Intubate, Can't Oxygenate (CICO) Scenario. These sessions have evolved from those run by Dr Andrew Heard in the 'Wet Lab' at the Royal Perth Hospital, Australia, using live anaesthetised sheep. We will be using sheep prosections and SimMan, but the algorithm, techniques and equipment you will be shown are identical to those produced by Dr Heard, and used across Australia. The principles underlying these are that of providing safe, simple, fast oxygenation via the anterior neck, using techniques that play to the strengths of anaesthetists. The material in this handout is adapted from work published by Dr Heard [1].

Airway Training

The session starts at **08:15** in the Simulator suite, lower floor of the *Horizon Centre.* You will initially be taken to the discussion room for an explanation of the algorithm used and an introduction to the practical techniques involved. We then move to the simulation lab where you will practise the procedures on sheep prosections. Finally we will place you in a simulated emergency CICO situation using SimMan. We aim to create as close to a "real life" atmosphere as possible. The "patient" will be desaturate and the pulse oximeter will alarm accordingly.. You will have the opportunity of practising the cricothyroidotomy techniques introduced in the sheep prosection session.

Safety Issues

You will be provided with gloves, aprons and masks to wear. Bear in mind that you will be working with raw animal tissue, sharps, liquids and an oxygen cylinder. Appropriate standards of hand hygiene and other safety precautions must be observed.

Participation

There is **no** obligation to participate. If you would rather not attend the session please contact any member of the SWEAT team in advance, via the Anaesthetics Department. Please note that we may collect anonymised data from the sessions for audit purposes. Occasionally we may film the sessions for teaching purposes, but you will be informed if this is the case.

CICV vs. CICO - Oxygenation does NOT require ventilation

The term “Can’t Intubate, Can’t Ventilate” (CICV) places too much emphasis on striving to achieve ventilation rather than life-saving oxygenation in the hypoxic patient. Keeping a patient alive with emergency oxygenation does NOT require normal minute ventilation and may, in fact, require no minute ventilation at all.

We propose that CICV be renamed “Can’t Intubate Can’t Oxygenate” (CICO), as oxygenation is of primary importance and carbon dioxide elimination is not immediately required. Jet ventilation in these circumstances should therefore be termed jet oxygenation. We use this terminology henceforth.

Management of the ‘Can’t Intubate Can’t Oxygenate’ (CICO) Scenario

The “Can’t Intubate, Can’t Oxygenate” (CICO) scenario is a rare event. In the Royal College of Anaesthetists’ Fourth National Audit Project (NAP4), of the estimated 2.9 million annual general anaesthetics, there were 11 cases in anaesthesia where emergency surgical access was performed as a true emergency for a patient in extremis [2].

All algorithms divide techniques for CICO management into either needle cricothyroidotomy or surgical cricothyroidotomy using a scalpel. The skills of an anaesthetist are greatly in favour of a cannula over a scalpel. Most emergency invasive airway attempts by anaesthetists in NAP4 involved the use of narrow bore cannula techniques. Timely progression through emergency algorithms is impeded when the operator is faced with pathway decisions, or choices, rather than prescriptive stepwise guidance (such as the Advanced Life Support cardiac arrest algorithm [3]). To reduce decision-making, and hence save precious time, in the stressful emergency situation, we recommend the use of a cannula technique in the first instance for the anaesthetist in all cases.

The body of evidence for specific techniques in the CICO scenario is not strong. A randomised double blind human study on emergency airway rescue techniques is not feasible and is also not the tool it should be assessed by. Observation of thousands of different attempts at emergency techniques in a stressful simulated environment, in the Perth Wet Lab over the last ten years has led to the production

of an algorithm, instruction booklet and refined equipment that aims to provide the best chance of successful intervention.

In this teaching we assume that all oxygenation attempts via the upper airway have been attempted and failed (e.g. the Plan A, +/- B and C sections of the DAS guidelines.

DAS and Plan D

In November 2015 DAS published its updated guidelines, Plan D is succinctly put as surgical cricothyroidotomy [4]. However a number of subsequent editorials and letters have highlighted that evidence provided for this recommendation comes from pre-hospital care and not an elective anaesthetic environment [5,6]. It also points out that with the right training and equipment a needle technique maybe superior for anaesthetists, and concedes that NAP 4 gave us no data on surgical techniques performed by anaesthetists. For these reasons, while it appears only surgical cricothyroidotomy is advised actually the paragraph discussing Plan D DAS advocates that anaesthetists must be practiced in both techniques.

As transition to the front of neck is one of the main barriers, by putting a needle in the anaesthetist hands first we hope to lessen that barrier and the paralyzing effect of choice under stress, thereby minimize delay. It has been further pointed out that a scapel first technique becomes a scapel only technique, as a subsequent cannula technique will be impeded by soiling of the trachea with blood [6].

DAS also highlights the lessons from NAP 4, that success depends on decision-making, planning, preparation, and skill acquisition, all of which can be developed and refined with repeated practice. By having standarised equipment, in every anaesthetic environment, and having repetitive didactic training reinforced by SIM training we hope this course will provide this practice.

Equipment

At Torbay Hospital we have produced two CICO packs which are located in a visible and easily accessible place in every anaesthetic room / area in the hospital where general anaesthesia is administered. This pack consists of all the equipment necessary to provide safe, simple and fast oxygenation.

CICO pack 1 contains:

- 14G Insyte™ cannula
- 5 ml syringe
- Rapid 0_2 device (used for jet oxygenation via the cannula using a standard oxygen flowmeter).
- A 10ml saline ampule is taped to the front of the pack
- In locations where the anaesthetic machine doesn't have an auxillary oxygen flowmeter, a 5mm ETT adapter is also taped to the front of the pack to allow oxygen tubing to be attached to the fresh gas outlet

CICO pack 2 contains:

- Scalpel with size 10 blade
- Frova™ bougie
- 15mm Rapi-fit™ connector
- Size 6.0 internal diameter cuffed endotracheal tube

The initial emergency equipment required to manage a CICO situation needs to be present in theatre and NOT be a request away.

Figure 1. *CICO pack contents*

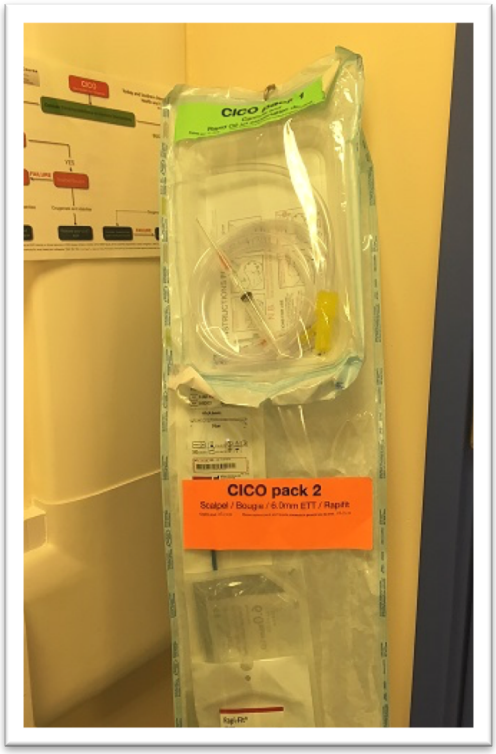


Figure 2. *14G Insyte™ cannula with the flashback chamber still connected.*

Figure 3. *'Rapid 0_2' jet oxygenating device. Luer-Lok™ tip (bottom right) connects to the cannula. T-piece (yellow) connects to oxygen tubing which in turn attaches to an oxygen flowmeter (15 L.min^{-1}).*

Figure 4. *The lower blue scalpel has a size 10 blade (rounded) and is contained within the CICO pack. The upper grey scalpel exhibits a much sharper profile and is less suitable for the required blunt stab incision.*

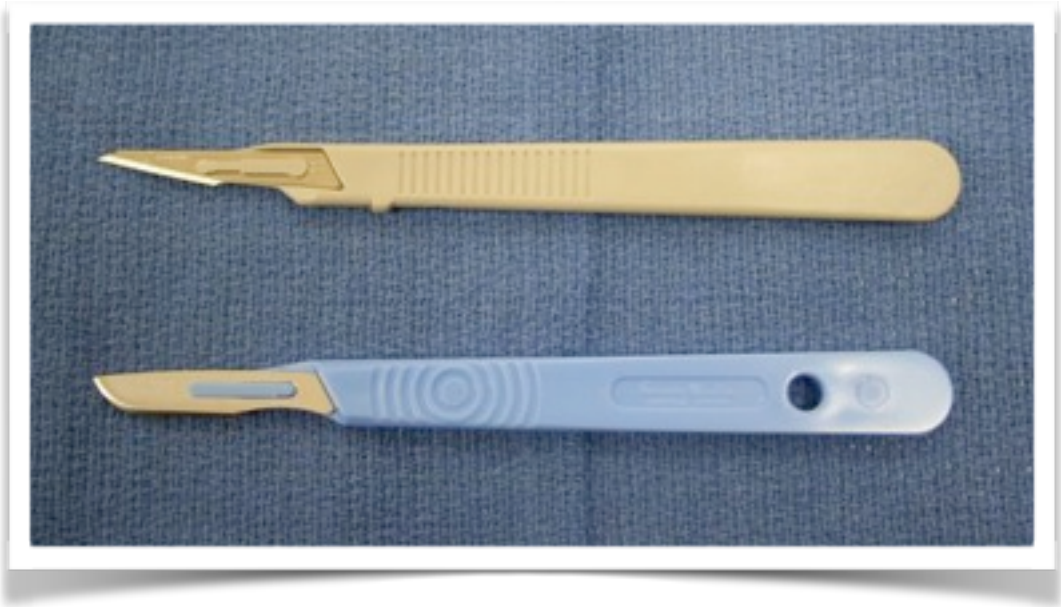


Figure 5. *15mm Rapi-fit™ connector (attach to Frova bougie, allowing ventilation via the bougie)*

This basic and inexpensive CICO pack provides all the equipment required to provide rescue oxygenation in the initial stages of the CICO scenario. Once life-threatening hypoxaemia has been treated, the arrival of the Difficult Airway Trolley will provide additional equipment such as the Melker™ size 5.0 cuffed emergency airway (see later section on the Melker™ Airway) to continue management of the CICO scenario.

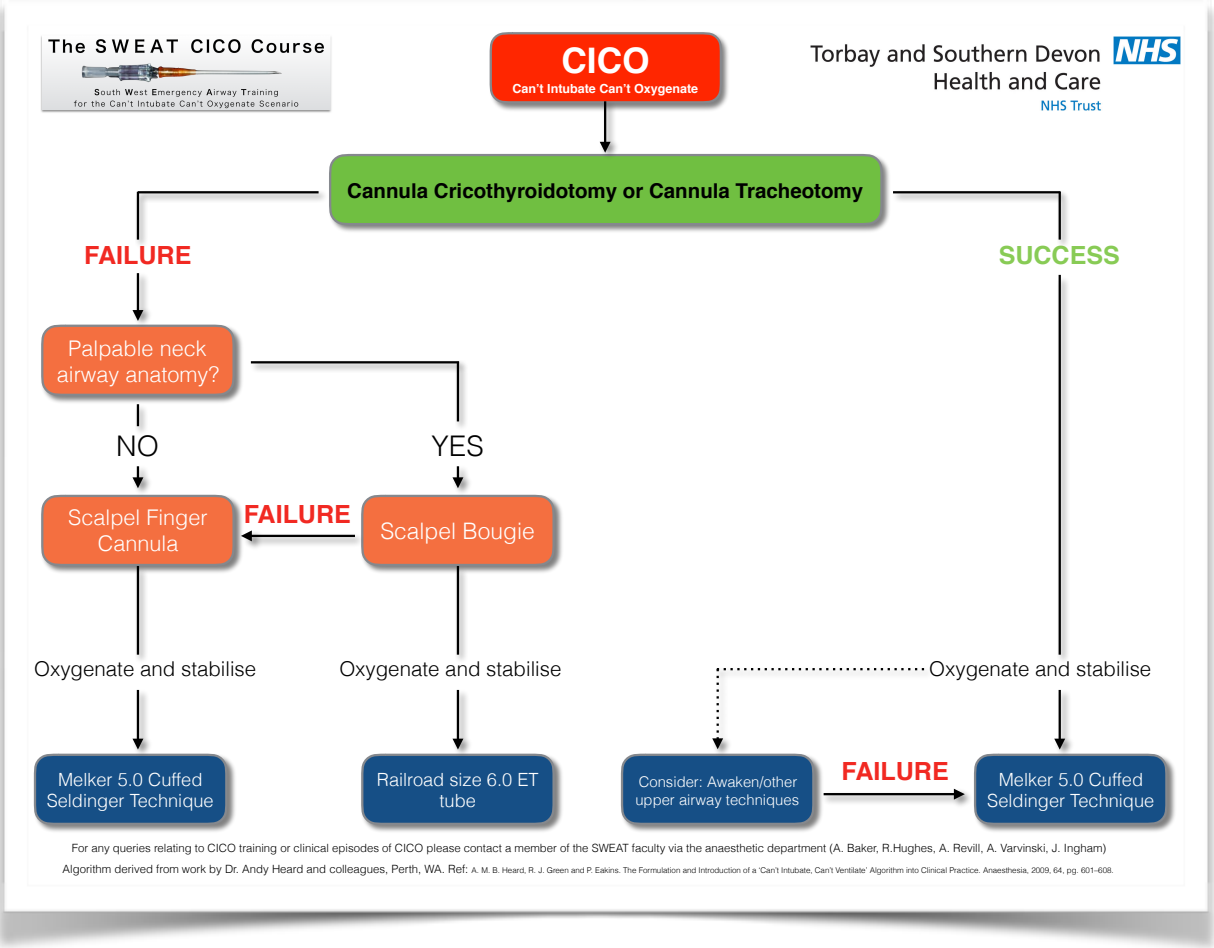
Cannot Intubate, Cannot Oxygenate (CICO) Algorithm for Anaesthetists

The following pages outline the recommended techniques for each of these stages and some of the thinking behind our recommendations.

Patient positioning

The ideal position would be to replicate that required for a surgical tracheostomy i.e. pillow removed, head ring under the occiput and sandbag under the shoulders to extend the neck. In reality this may be difficult to achieve during the CICO scenario. Sliding the patient up the bed / operating table allowing the head to hang off the top will provide neck extension and appropriate tension to the anterior neck tissues. Obviously care is needed during this manoeuvre, especially if neck injuries are present. It is also essential that throughout this process oxygen is applied via the upper airway (facemask or LMA) at all times. Apnoeic oxygenation may occur is there is a patent aperture between the upper airway and the alveoli.

Figure 6. *The CICO Algorithm*



Cannula Cricothyroidotomy or Cannula Tracheotomy

CICO algorithms commonly describe trans-tracheal access via the cricothyroid membrane. Experience in the wet lab has demonstrated that should the cricothyroid membrane not be palpable that certain individuals are unable to progress and have ceased attempts at rescuing the airway. Cannula tracheotomy is included in our algorithm as trans-tracheal access at this location is perfectly reasonable under the circumstances and it enables progression down the algorithm. It may be that neither the cricothyroid membrane nor the anterior trachea is palpable. The plan for a needle technique in this situation is considered below in the section Impalpable Anterior Neck Airway (IANA).

Choice of cannula & equipment

The 14G Insyte™ is our preferred cannula. This comes as part of the Rapid O2 pack, pre-mounted on the 5ml syringe

Figure 7. *The 14G Insyte™ cannula, syringe and saline*

Saline
Use of 2 mls of 0.9% saline in the 5 ml syringe provides a positive endpoint of bubbles when aspirating within an airway. If saline is not readily available then anterior neck airway access should not be delayed to acquire it.

Reasons for failure

1. Kinking of cannula
2. Blood / vomitus in the airway
3. Difficult Anatomy
4. No obvious reason - Included to prevent fixation errors

Cannula Cricothyroidotomy or Tracheotomy Insertion Technique

Identify the cricothyroid membrane. If this is not possible then identifying the trachea will be adequate for a needle cricothyroidotomy. Failing this the midline should be used. Stabilise the airway with non-dominant hand. Hold the syringe in the dominant hand with fingers between flange and plunger enabling an “aspirate as you go” technique. Insert the tip of the needle through the skin advancing whilst aspirating. Typically insertion should occur at 45° caudally but this is only appropriate in those with thin necks and easily identifiable anatomy. In the difficult neck where there is a lot of adipose tissue or anterior swelling it is then better to advance the needle perpendicular to the skin, otherwise there may be not enough length on the cannula to reach the trachea.

The end point of successful trachea cannulation is the aspiration of air identified by bubbles in the saline into the syringe. It is important to identify free aspiration up the whole length of the syringe rather than a purely vacuum induced movement of the plunger. (Releasing the plunger subsequently will confirm actual aspiration of air rather than a vacuum effect). Once aspiration has occurred up the whole length of the barrel of the syringe the non-dominant hand should move to stabilise the cannula via the hub, with the dominant hand moving underneath the syringe to hold and secure the trochar with a pencil grip resting the hand against the neck or chin. Advance the cannula over the needle into the airway with the non-dominant hand. The force required for this is greater than that involved in intravenous placement. It is important not to remove the trochar prior to advancement of the cannula as this will lead to kinking of the cannula. Once the cannula is advanced into the trachea, the trochar can be removed. At this point it is essential to hold onto the cannula to prevent inadvertent removal. Also it is imperative that before the cannula is used for jet oxygenation a “check” aspiration is performed. This should be performed with the same syringe as previously containing saline. A full aspiration up the barrel of the syringe with release of the plunger will confirm airway placement. If check aspiration fails then continued aspiration whilst withdrawing the cannula slightly can correct this and should be attempted as a common reason for this failure is due to impaction of the tip of cannula onto the posterior wall of the trachea and kinking of the cannula. Following confirmation of position, attach the cannula to a jet oxygenation source and begin oxygenation.

Jet Oxygenation technique

Figure 9. *Rapid 0_2 device - The 'on' jetting position (thumb occludes the remaining T- piece orifice).*

Jet oxygenation is the means by which oxygen is delivered to the patient via the cannula, traditionally using a device which delivers oxygen under high-pressure.

Unsafe jetting practice, particularly in the presence of partial or complete upper airway obstruction can lead to dangerously elevated intrathoracic pressure that may significantly impede cardiac output and cause barotrauma. The wet lab experience led to the formulation of a jetting plan for adult humans that minimises the risk of such adverse effects. The plan deprioritises ventilation and focuses on oxygenation. Whilst the risk of barotrauma is highest if there is *complete* expiratory obstruction, jetting may be performed successfully even in this situation. The plan involves infrequent jetting solely to maintain oxygenation, with subsequent jets only being given when the oxygen saturations begin to fall after initial recovery.

Jet oxygenation in the CICO scenario has two goals:

1. Provision of oxygen
2. Prevent / improve airway and alveolar collapse

The first step is to deliver a four-second re-inflation jet at a flow rate of 250-300 $ml.sec^{-1}$. This is produced by attaching the Rapid 0_2 to wall or cylinder oxygen, at $15l.min^{-1}$, and occluding the open limb of the t-piece for four seconds. Our goals when a cannula is used in this situation are not the same as for elective jet ventilation for airway surgery, as CO_2 elimination is not important in the time frame of the immediate rescue of a critically hypoxic patient. After successful re- oxygenation the question becomes 'how infrequently can one jet to maintain adequate oxygenation?'

Our animal data supports the premise that, in the CICO scenario, only relatively infrequent jetting is required to maintain oxygenation and that subsequent jets should only be delivered when the SpO_2 has started to fall again, after having peaked. Our suggestion is for a two-second jet using the Rapid 0_2 as described above, once $Sp0_2$ has dropped to 5% below the peak produced by the preceding jet. If $Sp0_2$ is not recordable, deliver a two-second jet every 30 seconds.

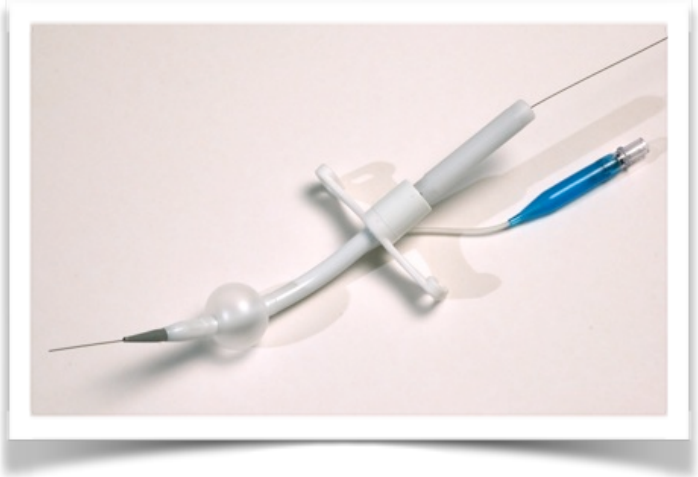
Anaesthetists are advised to read the section in Appendix 1, which expands on the rationale for this jetting plan, and Appendix 2, which describes why the Rapid 0_2 is the preferred jetting device.

Conversion to the Melker™ Airway

Cannula cricothyroidotomy or tracheotomy is the first step in the CICO algorithm followed by jet oxygenation. Allowing the patient to awaken at this point may be appropriate. Often however, a cuffed airway will be required. We recommend insertion of the Melker™ size 5.0 cuffed airway (Cook® Medical Inc., Bloomington, IN, USA) using the Seldinger technique for this purpose.

The Melker™ airway comes in a pack containing a scalpel, needle, wire and the airway itself (with introducer / dilator). According to our initial management, a cannula will already be in situ and the patient well oxygenated from jet oxygenation. This should allow the anaesthetist time to request, prepare and think through the steps required for Melker™ insertion.

Figure 10: *The Melker™ cuffed airway.*



Melker™ Airway Technique

During the explanation for insertion below, the introducer / dilator will be referred to as the “dilator” and the airway device (tracheostomy tube) which ultimately sits within the airway when in use will be termed the “airway”.

1. Insert the wire through the cannula (soft end of the wire first). Difficulty in passing the wire may be due to a kink in the cannula. Withdrawing the cannula slightly should allow the wire to pass. Plenty of the wire should be passed to prevent the wire being inadvertently removed during this technique.

2. Withdraw the cannula over the wire. If desaturation occurs prior to successful Melker™ insertion the cannula can be carefully passed back over the wire and jet oxygenation re- commenced.

3. Using the scalpel blade (size 10), make a stab incision along the wire pointing caudally to a depth of approximately 2 cms. Ensure that the wire is free to move within the incision with no skin tags present to hinder insertion of the Melker™ airway.

4. There is no locking mechanism which keeps the dilator fixed within the airway. Grip the dilator / airway unit to ensure that the airway remains fully ‘loaded’ on the dilator. The commonest reason for insertion failure is that the dilator slips back within the “airway” to some extent producing a “step” between the dilator and the tip of the airway when the unit is held incorrectly. We suggest the following “grip”:
    1. The Grip (see figure 12,13)
    2. Pick up the loaded dilator / airway unit with the palm of the dominant hand towards the concave curvature. It helps if one adopts the hand position in Figure 11
    3. Place the fourth and fifth fingers proximal to the flange (blunt end) gripping the dilator firmly within the airway. Allow space for the wire to pass out of the blunt end of the dilator close to the medial aspect of the palm
    4. Place the middle finger just distal to the flange
    5. Place the index finger near the tip of the dilator
    6. Place the thumb at the junction of the airway and remaining flange

5 Pass the wire through the dilator / airway unit via the tip.

6 Advance the combined dilator / airway unit over the wire in a caudal direction. Moderate force may be required especially if passing through trachea rather than cricothyroid membrane. If you are unable to advance the airway into the trachea then ensure that the dilator / airway unit is seated properly as described above. Also check the incision is in continuity with the wire and deepen / lengthen the incision as necessary.

7 The wire may become kinked making insertion difficult or impossible. In this instance repass a cannula over the wire and recommence jet oxygenation. A wire from a “central line” kit can be used as an alternative if no further Melker™ wires are available and a new one is required.

8 Once the airway is inserted fully, stabilise the 15mm connector, remove the dilator and wire in one motion, inflate the cuff and ventilate via self-inflating bag or anaesthetic circuit.

Figures 11: *Ideal hand position for picking the Melker™. The flange of the Melker™ goes between the parted fingers.* ***Figure 12:*** *"The Grip"*

Figure 13: *Index finger guiding the tip.*

Cannula cricothyroidotomy or tracheotomy failure

If cannula cricothyroidotomy or tracheotomy is unsuccessful after three attempts, then the anaesthetist must move to the left of the algorithm and perform a “scalpel” technique to access the airway.

If the anterior neck airway anatomy is palpable (cricothyroid membrane or trachea), the Scalpel Bougie technique is appropriate. If the anterior neck airway anatomy is impalpable, the Scalpel Finger Cannula technique will be required (see below).

Scalpel Bougie Technique

The scalpel bougie technique is reserved for cases of failed needle cricothyroidotomy, tracheotomy or jet oxygenation where the anterior neck anatomy is palpable. As highlighted above, most anaesthetists are unfamiliar with scalpels. Our observation of training in the wet lab has shown that in the stressful CICO scenario, scalpel incisions can often lead to excessive tissue destruction. It is for this reason that we advocate our scalpel bougie technique over the surgical cricothyroidotomy technique described in the ATLS course. The scalpel bougie technique, by way of only having a stab incision, reduces scalpel manipulation. The bougie is a piece of equipment that is familiar to the anaesthetist along with both the feel of its insertion and the process of railroading an endotracheal tube over it.

Some of the reasons for failure of needle cricothyroidotomy include blood or vomit in the airway making the end point of aspiration through a 14G cannula impossible. The scalpel bougie technique has a different endpoint (i.e. the feel of tracheal rings and “hold up”) and therefore may be successful where cannula cricothyroidotomy has failed. The Frova™ bougie also has the advantage of being hollow, enabling oxygenation and ventilation if required, via a 15mm Rapifit™ connector, prior to securing a cuffed airway.

Equipment

1. Frova™ bougie
2. Scalpel with size 10 blade - the blade needs to be wider than the width of the Frova bougie to enable insertion
3. Rapifit™ 15 mm connector
4. Size 6.0 cuffed endotracheal tube
5. Self-inflating bag or anaesthetic circuit

Technique

1. Identify cricothyroid membrane or anterior trachea. Stabilise with non-dominant hand.

2. With scalpel held vertically in dominant hand make a horizontal stab incision through cricothyroid membrane or anterior trachea with the cutting edge of the blade facing you.

3. Applying gentle traction towards you, rotate the blade 90° clockwise so that the cutting edge of the blade points caudally.

4. Gently pull / draw the whole scalpel towards you, maintaining a perpendicular alignment with the skin surface - this produces a triangular hole where the blade of the scalpel represents the side closest to you.

5. Now hold the scalpel with the non-dominant hand, thus allowing the dominant hand to manipulate the bougie.

6. Using the dominant hand, hold the bougie **parallel to the floor** with the blunt end away from you and the tip towards you and pointing towards the floor. Make contact between the tip of the bougie and the scalpel blade. Slide the bougie tip down the scalpel blade until it lies within the trachea.

7. Rotate and align the bougie to allow insertion along the long axis of the trachea i.e. raise the blunt end of the bougie into the air and as you do this, rotate it 90 degrees anticlockwise so it is becomes parallel with the longitudinal access of the body / trachea with the blunt end pointing in a cranial direction and the tip pointing anteriorly within the trachea. Now advance the bougie down the trachea. The feel of tracheal rings should be encountered and “hold up” should occur. If the feel of tracheal rings is not encountered then the bougie may be paratracheal. If the bougie is pretracheal, then “hold up” at the sternal notch will be encountered but the feel of tracheal rings will not. If the bougie has gone through the trachea into the oesophagus, there will be neither “hold up” nor the feel of tracheal rings encountered.

8. Remove the blade.

9. Re-oxygenate via the Frova™ bougie using the Rapifit™ 15 mm standard connector and self-inflating bag / anaesthetic circuit. Confirm placement of the bougie within the trachea with capnography. If a Rapifit™ connector is not available, a 14G Insyte™ cannula can be used for oxygenation: remove the needle from the cannula. Insert the cannula in the blunt end of the Frova™ bougie up to the hub. Connect the jet oxygenation device to the cannula hub. Grip the cannula hub and blunt end of the Frova™ bougie between the index finger and thumb of the non-dominant hand to prevent misplacement whilst oxygenating. Oxygenate as described above in the jet oxygenation section.

10. Remove the Rapifit™ connector and railroad a lubricated size 6.0 cuffed endotracheal tube (ETT) over the bougie. It is common to encounter “hold up” of the ETT tip at the skin surface. Continual rotation of the ETT as it is advanced down the Frova™ bougie prevents this and facilitates placement. Extension of the incision is not usually required.

11. Remove the Frova™ bougie.

12. Inflate the cuff and ventilate via the ETT. Confirm a capnographic trace. Secure the tube in position. Insertion of an ETT through the anterior neck is prone to producing an endobronchial intubation. We recommend that the ETT black line lies at the skin surface when intubating via the anterior neck.

Impalpable Anterior Neck Airway (IANA)

The cricothyroid membrane and trachea may be impalpable owing to pathology, neck adiposity, etc. Where an IANA situation exists, we still advocate a cannula technique for first line rescue oxygenation owing to anaesthetists' preference for cannula over scalpel techniques as stated earlier. In the wet lab an IANA situation is created by injecting saline under pressure into the anterior sheep neck to distort the airway and render it impalpable.

In the difficult neck where there is a lot of adipose tissue or anterior swelling it is better to advance the needle perpendicular to the skin, rather than at 45°, otherwise the cannula may prove too short to reach the trachea even when inserted to the hub. Once the trachea has been identified using the aspiration technique described, the needle can be angled slightly backwards as the cannula is advanced off to prevent the cannula kinking against the poster tracheal wall.

In the IANA situation, our recommendation is that the first cannulation attempt is performed in the midline unless there is information suggesting a trachea positioned to the contrary. If the first cannula attempt fails then we recommend that the second attempt be performed lateral to the first i.e. horizontally across the neck. The insertion attempt should remain in an anterior-posterior direction. It is unlikely that the trachea will be encountered if the cannula is aimed back towards the midline if a midline attempt failed to encounter it. The lateral attempt aims to hit a trachea advancing down the neck in a lateral position. Deviated tracheas are more likely to pass through the neck in an essentially superior to inferior course even if deviated laterally. If the second (lateral) cannula attempt fails then the third and final blind cannula attempt should be performed lateral to the midline on the other side (for the same reasons described for attempt two).

If three blind attempts fail to cannulate the trachea, then the scalpel finger cannula technique should be performed.

Scalpel Finger Cannula Technique

The scalpel finger cannula technique is the final, and most invasive, technique to provide oxygenation when previous oxygenation techniques have failed.

Indications for the scalpel finger cannula technique are:

1. Three failed attempts at cricothyroidotomy or tracheotomy where there is an Impalpable Anterior Neck Airway (IANA).

2. Two failed attempts at endotracheal insertion using the scalpel bougie technique.

The technique should be performed in the midline unless there is evidence that the airway is likely to exist in a more lateral position.

Equipment

- Scalpel with size 10 blade
- 14G Insyte™ cannula, 5 ml syringe and 2 ml 0.9% saline as per cannula

cricothyroidotomy / tracheotomy technique above

- Rapid 0_2™
- Size 5.0 cuffed Melker
- 10 ml syringe for Melker
- Self inflating bag or anaesthetic circuit

Technique

1 Secure the skin of the neck with the non-dominant hand. With the scalpel in the dominant hand make an 8-10 cm vertical incision in a caudal to cranial direction. The incision should be superficial, passing through skin and subcutaneous tissue only. A vertical midline incision avoids the great vessels located laterally.

2 The next step involves inserting the fingers of both hands into the incision to separate the strap muscles by blunt dissection i.e. stretch the strap muscles apart. This blunt dissection avoids the damage to these tissue planes caused by a more significant scalpel incision. A deeper incision may be required if the strap muscles cannot initially be identified and separated by the use of fingers.

3 Once the muscle planes are separated the non-dominant hand should be inserted into the incision to identify the airway structures. The tracheal rings, cricoid or thyroid cartilages should be identified keeping in mind that they may not be found in the midline. The trachea is identified by the undulating (bumpy) surface created by the tracheal rings and the fact that the fingers can get behind it. The vertebral column and sternocleidomastoid muscle are other structures commonly confused with the trachea. The vertebral column has a “bumpy” surface, but the fingers cannot get behind it. The fingers can get behind the sternocleidomastoid muscle, but the muscle is smooth with no “bumps”.

4 Whilst stabilising the airway structures with the non-dominant hand, a 14G Insyte™ can be inserted directly into the trachea using the same apparatus and aspiration technique as described in the cannula cricothyroidotomy / tracheotomy section.

5 Jet oxygenation may then be performed via the cannula as previously described above.

6 Following rescue oxygenation, a wire may be passed down the cannula followed by insertion of the size 5.0 cuffed Melker™ using the Seldinger technique. In contrast to the Melker™ technique described above, when one is inserting the Melker™ directly into the trachea, no incision along the wire using a scalpel blade is required prior to insertion of the dilator / airway unit.

TAKE-HOME POINTS

- Oxygenation is life-saving initially in the CICO situation. A cannula can provide emergency oxygenation and is the preferred technique for the majority of anaesthetists.

- Equipment for the initial management of the CICO situation should be immediately available wherever airway management is being performed.

- Ventilation can be postponed until rescue oxygenation has been performed and the patient has an airway other than a cannula.

- If you are unable to palpate the cricothyroid membrane but can feel the trachea, then perform a cannula tracheotomy.

- Never let go of the cannula.

- Only jet oxygenate while watching the chest rise and fall.

- We recommend the Rapid 0_2 for jet oxygenation as it allows for expiration, and hence flow and pressure relief, through the cannula between jets.

- The initial jet should be for 4 seconds.

- Jet oxygenate as infrequently as possible to minimise the risk of decreased cardiac
output and barotrauma.

- Second and subsequent jets should only be performed when the SaO_2 have fallen by 5% from the peak achieved with the previous jet.

- Second and subsequent jets should be of 2 seconds duration.

Further reading for anaesthetists

Appendix 1 – rationale for jetting plan

Carbon dioxide elimination is not immediately required in a CICO scenario

A cannula can be used safely in a CICO situation as long as the anaesthetist concentrates on treating hypoxaemia and abandons attempts to eliminate carbon dioxide (CO_2) (i.e. ventilation). It is this latter process which significantly increases the risk of high intrathoracic pressures and barotrauma and is unnecessary in the immediate treatment of a CICO situation. There is good evidence that, as long as oxygenation is maintained, a lack of CO_2 elimination for prolonged periods is not associated with any permanent adverse effects. Frumin published a series of experiments in 1959 in which paralysed, anaesthetised humans survived periods of apnoea up to 55 minutes without any ventilation [4]. The endotracheal tubes of intubated subjects were connected to reservoirs of 100% oxygen and oxygenation was well maintained in all subjects throughout the study by the process of apnoeic mass-movement oxygenation. In our algorithm we plan for jet oxygenation through a cannula to be a temporising measure until either a large-bore cuffed airway is inserted or the patient starts to breathe. It will often be only a matter of minutes before the cannula becomes superfluous or it is used as a conduit for Seldinger insertion of an airway such as a cuffed size 5.0 Melker™. In this time frame CO_2 accumulation will not have significant adverse effects and, therefore, the anaesthetist should not attempt to eliminate CO_2. Even jetting at a 'normal' respiratory frequency we believe this risk becomes unacceptable. The implication is that follow-up jets should only be delivered as required to maintain adequate oxygenation. With a narrow-bore cannula in situ, we deliver low frequency breaths at a high pressure (in the order of one hundred to four hundred kPa) that we term jet oxygenation.

Reduced lung volume and atelectasis in the CICO scenario

Reduced lung volume and atelectasis due to prolonged apnoea is a feature of the CICO scenario. During apnoea, oxygen removal from the lungs is at a rate of approximately 250 $mls.min^{-1}$. CO_2 dissolves in body tissues and fluids to such an extent that only about 10% of metabolically- produced CO_2 (approximately 20 $ml.min^{-1}$) is added to the alveoli [5]. As a consequence there is a reduction in alveolar pressure and a pressure gradient is generated between the upper airway and alveoli. If the upper airway is patent, external gas is drawn en masse into the lungs and this is the basis of apnoeic mass-movement oxygenation. If the upper airway is closed to inspiration, as in the CICO scenario, the lung volume will progressively reduce and intrathoracic pressure will rapidly become sub-atmospheric and continue to decrease at a rate dependent upon thoracic compliance. The effect is strong enough to produce a sub-atmospheric pressure of 40 cmH_2O within eight minutes in the oxygen-filled lungs of paralysed dogs. As the apnoea time extends there will inevitably be increasing atelectasis and ventilation/perfusion (V/Q) mismatch that will subsequently make re-oxygenation more difficult when jetting is initiated. As low lung

volumes are inevitable when the first rescue jet is delivered, that initial jet can usefully be of a reasonably large volume.

The initial rescue jet in adult humans

For the reasons discussed, an effective and safe approach to jetting involves the delivery of one relatively large reinflation jet followed by subsequent jets only as required to maintain adequate oxygenation. This is the standard technique used for the last four years during weekly training sessions in Perth involving the live, anesthetised sheep.

The initial jet in a CICO scenario should be long enough to achieve adequate lung expansion in the potentially difficult-to-oxygenate patient with a relatively patent upper airway but not so long as to cause raised intrathoracic pressure and barotrauma in a patient with complete upper airway obstruction. When extrapolating our data from sheep to humans it is useful to be aware that lung volumes are roughly proportional to body mass for all mammals [6]. More precisely larger mammals tend to have slightly larger lung volumes per unit mass than smaller mammals. Having conservatively upscaled the volume of the rescue jet from that used successfully in sheep, we suggest **a four-second inspiratory period is an appropriate initial rescue jet** for an adult human when using a cannula and jetting apparatus combination that will deliver a flow rate of 250-300 $ml.sec^{-1}$, and so an initial volume of 1000-1200 mls.

Data recorded from a sample of wet lab sheep, and representative of the last 1000 scenarios that have been run, show a median delay of 13 seconds (range 6 to 48 seconds) before $Sp0_2$ began to rise. All sheep were adequately reoxygenated after a single jet with the median peak $Sp0_2$ reached being 96% (interquartile range 92-98%; range 82 to 100%; peak $Sp0_2$ data recorded for 38 scenarios). Please see Dave Lacquiere if you would like more information on these data, and for other animal and human data which support these findings.

Second and subsequent jets

Assuming the response to the initial jet is adequate, subsequent jets should only be delivered in such a way as to maintain oxygenation and avoid iatrogenic damage. Having decided not to actively attempt to eliminate CO_2, the fundamental question has changed from ‘how often should one jet safely’ to ‘how infrequently can one jet to maintain adequate oxygenation’. It is clear from our data that there is considerable variation in how long oxygenation is sustained after the initial jet and as a result there will also be variation in how infrequently one can jet. If SpO_2 is recordable then it will be the best measure as to the adequacy of oxygenation and should be used to inform the timing of second and subsequent jets. We recommend that if adequate SpO_2 is achieved in response to the initial jet then delivery of a subsequent jet should be discouraged until after the SpO_2 has started to drop again. In our training sessions we **deliver a subsequent jet when the SpO_2 falls by 5% of the peak SpO_2 achieved after the preceding jet**. For example if peak SpO_2 of 95% is achieved after the first rescue jet we will not deliver a second jet until the SpO_2 has fallen to 90%. This may be a surprisingly long time and from our data in the wet lab we did not

deliver the second jet until a median of 98 seconds after the first. Assuming the response to the first jet is acceptable, we extrapolate from our experience in sheep that a **two-second duration is reasonable for the second and subsequent jets** in adult humans given an oxygen flow rate of 250-300ml.sec^{-1} and hence volumes of 500-600mls.

Patients with total upper airway expiratory pathway obstruction are at the highest risk of barotrauma and adverse cardiovascular effects. However, even if there is total expiratory airway obstruction and expiration is dependent on gas flow out of the cannula, as one litre of gas can easily be passively expired from a patent 14G cannula within 1 minute, it should be safe to insufflate up to 1 L.min^{-1} without causing unacceptable 'stacking' of breaths and risking barotrauma [7]. Trans-tracheal jet insufflation in a large animal model with complete

upper airway obstruction and profound hypoxia led to excellent recovery as determined by both blood gas analysis and haemodynamics when volumes in the region of 2 L.min^{-1} were insufflated [8].

Failure to correct hypoxia

It is usual to expect a rapid improvement in oxygenation after a large volume initial rescue jet. In our series we observed that SpO_2 began to improve within twenty seconds of the initial jet in 50 out of 56 scenarios. If there has not been a significant improvement in SpO_2 after twenty seconds then, assuming there was obvious evidence that oxygen was delivered into the trachea, the problem may relate to very deranged haemodynamics or inadequate gas exchange in the lungs. It is possible that patients with extensive atelectasis (pre-existing or developed during closed airway apnoea), other lung pathology or obesity, will require a certain degree of lung re- expansion (as opposed to just delivery of oxygen) in order to enable satisfactory oxygenation. If a jet of too low flow is delivered to these patients in the presence of low resistance to expiration then lung inflation may be inadequate as a large proportion of gas will escape directly out of the upper airway (likely to be audible). In these circumstances high flows, such as those achieved with a Manujet set at 3-4 bar, may be required in order to achieve adequate lung re-expansion.

Oxygenation may be problematic in such patients even with conventional positive pressure ventilation.

Expiration and jetting frequency

During and immediately after the initial jet it may become apparent if there is a patent expiratory pathway as gas may be heard escaping or the chest will be seen to fall. After any jet it is important to ensure that expiration occurs via either the cannula or upper airway. If the presence of a patent expiratory pathway is not clear, and it is not already being done, then upper airway opening manoeuvres, airway adjuncts or a laryngeal mask airway insertion (ideally with oxygen attached in case entrainment occurs) should be employed.

Safe jetting under extreme stress

Guidance for jetting in a CICO scenario must be reproducible under extreme stress and, in particular, ensure that progressive lung over-inflation does not occur. It must account for the CICO scenario being an unpredictable and dynamic situation with no guarantee of the continued expiratory patency of the airway or a cannula. At any time upper airway obstruction may increase due to swelling, secretions or blood clot, and the cannula may kink or plug off with secretions or clot. In the past in the wet lab, we used to instruct that the second and then subsequent jets should be given when the chest volume appears to have returned to baseline. However, we observed that some anaesthetists would struggle to put this instruction into practice and jet with dangerously high frequency and stack breaths. Under stress we have observed that there is a psychological tendency to jet at a higher rather than lower frequency and it is necessary to have a jetting plan that counteracts this. Delaying second and subsequent jets where possible until the SpO_2 has peaked and is falling again changes the emphasis from delivering as many jets as possible to as few jets as possible and so greatly reduces the potential for causing harm. As the focus is on oxygenation, SpO_2 is the logical parameter to use to guide jetting. If there has been circulatory collapse and SpO_2 is unobtainable then the anaesthetist should be conscious that only infrequent jetting is required to maintain oxygenation. In such cases it is necessary to resort to fixed frequency jetting and it is our estimation that a two-second duration breath given every 30 seconds will in most cases deliver enough oxygen to achieve an adequate alveolar partial pressure of oxygen (P_AO_2) without causing breath stacking. This is comparable to the delivery of paired breaths approximately every 20 seconds as per the American Heart Association Guidelines for Cardiopulmonary Resuscitation (compression–ventilation ratio of 30:2 for an adult in cardiac arrest when no advanced airway is in place) [9]. Whilst using the Manujet in the early days of the wet lab, when follow-up jets were delivered as soon as the chest had visibly recoiled, it was not infrequent that if the Manujet was detached for any reason (e.g. in order to convert a cannula to a Melker™) the SpO_2 would actually increase. In those situations it is likely that high intrathoracic pressure had built up with too frequent jetting and that cardiac output was compromised. The subsequent improvement in SpO_2 in these cases was due to an increase in cardiac output as intrathoracic pressure reduced when exhalation was able to occur during disconnection. Jetting timed to occur only after SpO_2 has peaked, and is falling again, will reduce the chance of the hyperinflation and high intrathoracic pressure that may occur with a, potentially unrecognised, obstructed expiratory pathway.

Appendix 2 – rationale for use of Rapid 0_2 over other jetting devices

Safe jetting apparatus

In order to avoid barotrauma, the jetting device must provide a flow rate that allows the anaesthetist to have control over the volume of each jet. Too high a flow rate is likely to be associated with variable and hence potentially large and dangerous jet volumes. A Manujet™ (VBM Medizintechnik, Sulz, Germany) achieves flow rates of more than 600 $ml.sec^{-1}$ through a 14G cannula with a driving pressure set at 2.5 bar [10]. For this reason it should be used with caution on these high settings. Oxygen delivery device and cannula combinations that deliver lower flows in the region of 250-300 $ml.sec^{-1}$ offer a reasonable compromise between safety and effectiveness. When used with a 14G cannula this can be safely achieved with the Rapid 0_2 jetting device (Figure 4,9), when driven by an oxygen flowmeter set at 15 $L.min^{-1}$. A Manujet™ set at 0.5-1 bar will also deliver flow rates in the region of 250-300 $ml.sec^{-1}$ [11].

The second key characteristic of a jetting device is that between jets the device should enable pressure relief and expiration through the cannula. Users should be aware that a significant disadvantage of the Manujet™ is the complete lack of expiratory flow and hence pressure relief via the device during expiration when it is connected directly to a cannula [12]. There is also great risk of barotrauma if oxygen is delivered from a flowmeter by a rudimentary three-way tap and oxygen tubing device (Figure 14) as, even when the side port is not occluded, there is neither pressure nor flow-relief (jet paper refs 17-19). In fact during supposed 'expiration' i.e. no active jetting, flow will continue into the trachea and dangerously high intrathoracic pressures may be generated. The Rapid 0_2 requires one large hole to be occluded to deliver an inspiration. Usefully, when it is uncovered during expiration this hole can then act as a pressure and flow relief vent [12-14]. For this reason we advise that this device is the safest option for use in a CICO scenario.

Figure 14. *Rudimentary three-way tap connected to oxygen tubing.*

Advantages of the Rapid 0_2 as a Jet Oxygenation Device compared to others

1. Non-expensive allowing it to be stocked wherever airway management is being performed

2. Connects to a standard oxygen flowmeter

3. Standard Leur-Lok™ connection at patient end of the device

4. Only one hole requires occlusion (with thumb) in order to jet oxygenate (cf Enk Oxygen
   Flowmeter, which requires five holes to be occluded).

5. Tactile feedback as to the adequacy of jet oxygenation i.e. readily palpable resistance
   against thumb if cannula kinked

6. In the non-jetting position, the lumen is of sufficient calibre to allow both flowmeter
   oxygen to vent to the atmosphere and expiration of gas from the lungs.

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