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Respiration and the Airway

RESPIRATION AND THE AIRWAY

Front-of-neck airway rescue with impalpable anatomy during a simulated cannot intubate, cannot oxygenate scenario: scalpel–finger–cannula *versus* scalpel–finger–bougie in a sheep model

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Abstract

Background: Front-of-neck airway rescue in a cannot intubate, cannot oxygenate (CICO) scenario with impalpable anatomy is particularly challenging. Several techniques have been described based on a midline vertical neck incision with subsequent finger dissection, followed by either a cannula or scalpel puncture of the now palpated airway. We explored whether the speed of rescue oxygenation differs between these techniques.

Methods: In a high-fidelity simulation of a CICO scenario in anaesthetised Merino sheep with impalpable front-of-neck anatomy, 35 consecutive eligible participants undergoing airway training performed scalpel–finger–cannula and scalpel–finger–bougie in a random order. The primary outcome was time from airway palpation to first oxygen delivery. Data, were analysed with Cox proportional hazards.

Results: Scalpel–finger–cannula was associated with shorter time to first oxygen delivery on univariate (hazard ratio [HR]=11.37; 95% confidence interval [CI], 5.14–25.13; $P<0.001$) and multivariate (HR=8.87; 95% CI, 4.31–18.18; $P<0.001$) analyses. In the multivariable model, consultant grade was also associated with quicker first oxygen delivery compared with registrar grade (HR=3.28; 95% CI, 1.36–7.95; $P=0.008$). With scalpel–finger–cannula, successful oxygen delivery within 3 min of CICO declaration and ≤2 attempts was more frequent; 97% *vs* 63%, $P<0.001$. In analyses of successful cases only, scalpel–finger–cannula resulted in earlier improvement in arterial oxygen saturations (−25 s; 95% CI, −35 to −15; $P<0.001$), but a longer time to first capnography reading (+89 s; 95% CI, 69 to 110; $P<0.001$). No major complications occurred in either arm.

Conclusions: The scalpel–finger–cannula technique was associated with superior oxygen delivery performance during a simulated CICO scenario in sheep with impalpable front-of-neck anatomy.

Keywords: airway management; cannot intubate cannot oxygenate; emergency front-of-neck airway; oxygen delivery; scalpel finger bougie; scalpel finger cannula

Editor's key points

- Emergency front-of-neck airway is regarded as the last resort in a cannot intubate, cannot oxygenate (CICO) scenario, but it is not known which method is better.
- In a high-fidelity simulation of a CICO scenario in anaesthetised sheep, scalpel–finger–cannula and scalpel–finger–bougie methods were compared.
- The scalpel–finger–cannula method was found to be associated with shorter time to first oxygen delivery.

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The cannot intubate, cannot oxygenate (CICO) scenario accounts for a significant proportion of anaesthesia-related severe harm and death.[1] Dedicated training on CICO rescue techniques has become ubiquitous for anaesthetists internationally, with a focus on improving performance and patient outcomes during airway crises. Rescue techniques are particularly challenging when obesity or localised pathology render the front-of-neck airway anatomy impalpable, and these factors in turn raise the likelihood of CICO.[2,3] Consequently, guidelines on CICO management increasingly acknowledge the necessity for techniques that are effective when airway anatomy is impalpable, and simpler, less invasive techniques are impossible or have failed.[4,5]

The Royal Perth Hospital CICO training course has taught the scalpel–finger–cannula technique with impalpable front-of-neck anatomy for more than 10 yr.[5] This requires an 8–10 cm vertical incision with a scalpel in the perceived neck midline, followed by finger-based blunt dissection until the airway (cricothyroid membrane or trachea) can be palpated. A cannula is then inserted using the same standardised approach as that used for palpable front-of-neck anatomy (www.youtube.com/watch?v=0c6GPV_8t2U). Percutaneous emergency oxygenation is subsequently delivered via the cannula with a Rapid-O_2® (Meditech Systems Ltd, Shaftesbury, UK), a purpose-designed device that minimises the risk of barotrauma.[6] This approach prioritises rapid oxygenation, followed by controlled placement of a definitive cuffed airway. All Royal Perth Hospital CICO teaching is based on the prior performance of anaesthetists executing a variety of rescue techniques (more than 10 000 to date) in anaesthetised sheep, a model that represents a high fidelity simulation of the CICO scenario in a clinical setting.[5]

An alternative technique with impalpable front-of-neck anatomy, scalpel–finger–bougie, was described and recommended for the first time in the 2015 Difficult Airway Society guidelines.[4] This similarly requires an 8–10 cm midline vertical incision with a scalpel, and finger-based blunt dissection until the cricothyroid membrane can be palpated. A size 6.0 tracheal tube is then inserted, using the same standardised scalpel–bougie approach as that used for palpable front-of-neck anatomy (www.das.uk.com/content/video/fona). Thus, oxygenation and ventilation are achieved simultaneously.

The technical skills required to perform airway rescue techniques with impalpable front-of-neck anatomy are considerable, and a major departure from the normal anaesthesia skill set. Extensive bleeding can be expected from the 8–10 cm midline vertical neck incision, and although the airway may ultimately become palpable it will not necessarily be visible. The insertion trajectories and manoeuvrability of rescue equipment may also be limited by adjacent soft tissue. The scalpel–finger–cannula and scalpel–finger–bougie procedures differ in their reliance on airway visibility and equipment manoeuvrability, and differ in terms of the feedback they provide after successful airway puncture. The optimal approach in the impalpable front-of-neck scenario therefore remains unclear. We set out to explore the hypothesis that rescue oxygenation during a simulated CICO scenario in anaesthetised sheep with impalpable tracheas can be achieved more rapidly with a cannula-based approach.

Methods

This study in 35 sheep at the Royal Perth Hospital animal training facility was approved by the Royal Perth Hospital Animal Ethics Committee on October 26, 2017 (T 101/17–20). The animal training facility is licensed by the Department of Primary Industries and Regional Development, the state regulator for animal based teaching and research. All work is compliant with the Australian Federal Government National Health and Medical Research Council code for the care and use of animals for scientific purposes (8th edition, 2013) and the Western Australian Animal Welfare Act 2002. Reporting in this paper adheres to the Animal Research: Reporting of *In Vivo* guidelines.[7]

After the publication of the Difficult Airway Society guidelines in 2015, the scalpel–finger–bougie technique was incorporated into the airway teaching regimen at the animal training facility (which is henceforth referred to as the 'wet lab'). The scalpel–finger–bougie *vs* scalpel–finger–cannula in a sheep model study was registered in May 2018 (PCTE0000114; www.preclinicaltrials.eu), and data were collected on consecutive, eligible wet lab participants between May 2018 and July 2019. As per routine, prospective participants were sent pre-course educational material including step-by-step instructions, figures, and video links for each of the required techniques. Participants then provided written informed consent to take part, acknowledging the use of performance data for research and refinement purposes and the right to decline participation at any point.

Experimentally naïve male and female Merino sheep with standard commercial health status (body weight, 40–50 kg) were used. Animal housing (conventional raised pens), preparation, and monitoring were overseen by dedicated veterinary nursing staff, a veterinary anaesthetist, or both. Animals were premedicated with i.m. acepromazine 0.03 mg kg^{-1} and buprenorphine 0.01 mg kg^{-1}. Forty-five minutes later, anaesthesia was induced with i.v. midazolam 0.25 mg kg^{-1} and ketamine 5 mg kg^{-1}, and tracheal intubation was performed. Continuous monitoring included arterial oxygen saturation (SpO_2), capnography, heart rate, ECG, and invasive arterial blood pressure. Anaesthesia was maintained with i.v. infusions of midazolam 0.75 mg kg^{-1} h^{-1}, ketamine 3 mg kg^{-1} h^{-1}, and xylazine 0.3 mg kg^{-1} h^{-1}. A stable surgical plane of anaesthesia was achieved for 15–30 min before administration of i.v. vecuronium 0.1 mg kg^{-1}. This dosing regimen delivers analgesic and anaesthetic agents in excess of the accepted veterinary standard for i.v. anaesthesia in small ruminants, the triple drip approach.[8] At study end, animals were euthanised with i.v. pentobarbitone 160 mg kg^{-1}.

Weekly wet lab training days were attended by two participants. With an instructor present, training videos for each procedure were played. Participants subsequently practised each procedure on a Frova Crico-Trainer neck model (VBM, Sulz am Neckar, Germany), and any errors of understanding or technical execution were corrected. Meanwhile, two anaesthetised sheep were positioned supine in rooms resembling operating theatres, with the shaved front-of-neck exposed (approximately 30 cm). A permanent marker was used to delineate zones of the exposed neck into those used for palpable neck procedures (14 cm extending caudally from chin area) and those used for impalpable neck procedures (16 cm extending cranially from chest) (Fig. 1). The impalpable zone was further sub-divided into two 7 cm sections, referred to as cranial and caudal, respectively.

As per the routine training schedule, participants systematically performed the full range of rescue procedures during simulated CICO scenarios, with alternation of roles on sheep 1 and 2 (Supplementary Table S1). Cannula and scalpel-based techniques were carried out first in the palpable zone

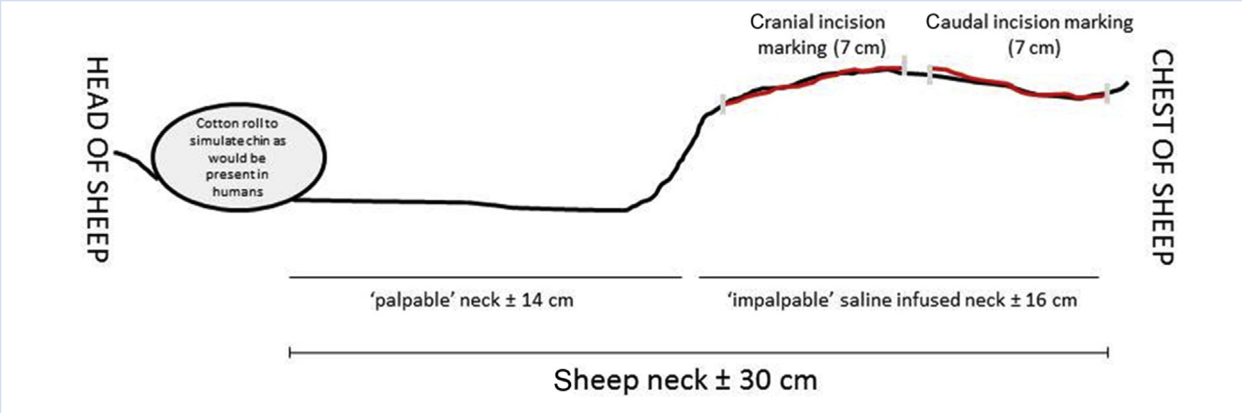

Fig 1. Sheep neck preparation creating four sections for training; cricothyroid membrane, palpable trachea, cranial impalpable trachea and caudal impalpable trachea.

(cricothyroid membrane and trachea, no data collection) and then in the impalpable zone. Data for this study were only collected during scalpel–finger–bougie and scalpel–finger–cannula techniques performed by participant 1 on the impalpable zone of sheep 1, if the eligibility criteria were met (see below). For logistical and study design reasons, data were not collected on sheep 2.

Once procedures on the cricothyroid membrane and palpable trachea were complete, participants debriefed with an instructor whilst a second instructor set up the impalpable neck sections. A cuffed parker tip tracheal tube size 7.0 mm was inserted through the most caudal tracheotomy established during the palpable neck training to isolate the impalpable neck zone. Suction via this tracheal tube was used to clear the trachea caudally of blood and clots if present (checked with flexible bronchoscopy). The tip of the tube was cut to minimise the likelihood of contacting the end of the tube during subsequent procedures. Surgical staples were applied at each end of the 7 cm lines previously marked out, making it impossible to extend a midline vertical incision beyond these limits. Circumferential ties were placed across the two staple lines demarcating the cranial impalpable section and saline was infused into this zone until the distance between the skin and trachea was $\geq$28 mm as measured by ultrasound. After the procedure in the cranial impalpable section, ties were repositioned and saline was infused into the caudal impalpable section until a distance between the skin and trachea was again $\geq$28 mm. The second procedure was then performed.

Data for the study were collected on sheep 1 if the following eligibility criteria were met: wet lab participant 1 was an anaesthetic registrar or consultant; an instructor dedicated to data collection only was available; the sheep physiology was judged stable enough to withstand 3 min of hypoxia; the SpO_2 trace was reliable before the commencement of procedures in the impalpable zone; and a tracheal depth $\geq$ 28 mm could be achieved following the method described above.

After the incorporation of scalpel–finger–bougie into the routine wet lab training, the sequence of procedures in the impalpable zone for all wet lab participants was randomised using a web-based tool with variable block sizes (www.sealedenvelope.com).

Thus, participants meeting the study eligibility criteria performed either scalpel–finger–bougie first in the cranial impalpable section, followed by scalpel–finger–cannula in the caudal impalpable section, or *vice versa*.

After randomisation of the procedure order, a CICO scenario was simulated. Mechanical ventilation was ceased, and a 3 ml syringe with the plunger removed was used to cap the oral tracheal tube and simulate partial upper airway obstruction. SpO_2 was allowed to decrease to $\leq$80%, at which point a CICO situation was declared by the instructor and the candidate commenced the designated rescue procedure. To avoid hypoxia-induced harm, successful oxygen delivery was required within 3 min of declaration of CICO and within two or less rescue attempts, after which ventilation with 100% oxygen was re-started via the oral tracheal tube. Lung function was then optimised with recruitment manoeuvres and suctioning as required. If hypoxia-induced instability was extreme or persisted despite remedial measures, the sheep was killed by attending veterinary staff.

Data collection and statistical analysis

Baseline data were collected on participant grade (registrar or consultant); experience in anaesthesia; previous Royal Perth Hospital wet lab attendance; date of any other CICO training received; and the actual pre-tracheal tissue depth achieved in the impalpable neck setup. Outcome data included the following times measured from time zero when the CICO scenario was declared by the instructor: time participant declares palpation of trachea after midline vertical incision and finger dissection; time participant declares tracheal puncture; time participant completes bougie insertion or check aspiration of cannula; time of first oxygen delivery (further defined for scalpel–finger–bougie as the time of first use of self-inflating bag with normal resistance and associated chest rise, and for scalpel–finger–cannula as time of thumb occlusion of Rapid-O_2® device with no feedback of obstruction); time of first improvement in SpO_2; and time of first end-tidal carbon dioxide (CO_2) reading. As participants performed tracheal palpation, tracheal puncture, and bougie insertion or check aspiration, they were asked to declare if they were confident in the procedure up to that stage with a yes or no response. If participants did not give a response before proceeding to the next stage, 'not confident' was recorded.

Overall procedure success was defined as oxygen delivery within 3 min of declaration of a CICO scenario and within two or less rescue attempts. Any major complications were documented including barotrauma, excessive bleeding and cardiac arrest. Data were double-entered into a spreadsheet by two investigators separately (AT and HP), and any discrepancies were adjudicated by a third investigator (SD).

The primary outcome was the time interval in seconds from palpation of trachea to first oxygen delivery. Sample size calculations were conducted to have 80% power at a significance level of 0.05 to detect a difference in the primary outcome of 60 s in the scalpel–finger–cannula arm *vs* 90 s in the scalpel–finger–bougie arm, assuming a standard deviation of 30 s (based on prior data collected in the wet lab). This resulted in a target sample size of 32 participants. Anticipating that 10% of sheep would meet at least one exclusion criterion after procedures in the cranial impalpable section, the sample size was inflated to 35. Secondary outcomes included overall success rates in each arm, time to first improvement in SpO_2 and time to first end-tidal CO_2 reading.

Data were summarised using mean and standard deviation (SD), median and first to third quartiles (Q1, Q3), or counts and proportions as appropriate. The primary outcome was analysed with a multivariable Cox proportional hazards model with shared frailty, treating failed oxygenation attempts as censored, and observations from the same participant to share the same frailty. Step-wise backward elimination was used to arrive at the final variables in the model. The association of CICO rescue technique and overall success was assessed with McNemar's test for binary matched pairs. Other secondary outcomes were analysed with a linear mixed model, treating participant as a random effect. Statistical analysis was performed using Stata v.15 (StataCorp LLC, College Station, TX, USA) and statistical significance was set at $P<0.05$.

Results

Fifty-three consecutive wet lab participants were assessed for study eligibility from May 2018 to July 2019 (Fig. 2). Thirty-five participants were enrolled including registrars ($n=21$) and consultants ($n=14$) with a median (Q1–Q3) of 5 (4–8) and 18 (12–27) yr of experience in anaesthesia, respectively. Almost all registrars had received previous CICO training (95%, median 1.5 yr prior) and 19% had attended the wet lab before. All consultants had received previous CICO training (median 2.9 yr prior) and 64% had attended the wet lab before. The median (Q1–Q3) tracheal depth before execution of the CICO procedure was similar in the scalpel–finger–cannula and scalpel–finger–bougie arms; 33 (30–36) *vs* 32 (29–36) mm.

On univariate time-to-event analysis, scalpel–finger–cannula was significantly associated with shorter time to first oxygen delivery compared with scalpel finger–bougie; hazard ratio (HR)=11.37, 95% confidence interval (CI) 5.14–25.13, $P<0.001$. Consultant grade and previous wet lab training were also associated with shorter time to first oxygen delivery (Table 1). Multivariate modelling retained only two variables: the scalpel–finger–cannula approach (HR=8.87; 95% CI, 4.31–18.18; $P<0.001$) and consultant grade (HR=3.28; 95% CI, 1.36–7.95; $P=0.008$). The association between the CICO rescue approach and time to first oxygen delivery was not found to vary with the grade of the participant ($P=0.245$ for interaction). The magnitude of the influence of these variables is depicted in Figure 3. The number (%) of participants delivering oxygen within 60, 120, and 180 s of tracheal palpation with scalpel–finger–cannula was 20 (61), 28 (85), and 32 (97), respectively, and with scalpel–finger–bougie was 3 (9), 21 (60), and 22 (63), respectively.

In mixed-model analyses restricted only to participants where front-of-neck-access was ultimately successful, time from palpation of trachea to clinical improvement in arterial oxygen saturations was shorter with scalpel–finger–cannula compared with scalpel–finger–bougie (−25 s; 95% CI, −35 to −15; $P<0.001$), but time to first capnography reading was longer (+89 s; 95% CI, 69–110; $P<0.001$). Successful delivery of oxygen within 3 min of declaration of a CICO scenario and within two or less attempts was more likely in the scalpel–finger–cannula arm; 97% *vs* 63%, $P<0.001$. Success rates for each attempt and time endpoints from declaration of a CICO scenario (rather than from palpation of trachea as for the primary outcome) are also summarised in Table 2. Participant confidence at each stage and subsequent oxygen delivery success during the first attempt of scalpel–finger–cannula and scalpel–finger–bougie is summarised in Table 3. No major complications occurred in either arm.

Discussion

In a high-fidelity simulation of the CICO scenario with *impalpable* front-of-neck anatomy, we found oxygen delivery was quicker when airway rescue attempts used a scalpel–finger–cannula approach compared with a scalpel–finger–bougie approach, and when the rescue operator was a consultant rather than a registrar. Successful oxygen delivery within 3 min of declaration of a CICO scenario, with no more than two attempts at front-of-neck access, was also considerably more likely with scalpel–finger–cannula. These results are consistent with those recently published by Rees and colleagues[9] in a *palpable* airway anatomy anaesthetised sheep model, where a cannula approach led to quicker oxygen delivery in successful cases, and a greater overall success rate.

The difference in time to first oxygen delivery reported here is clinically significant. In the wet lab, the transition from tachycardia to bradycardia to peri-arrest during induced hypoxia frequently occurs within a 30 s timeframe. This was therefore selected as a clinical significance threshold and formed the basis of our sample size calculation. The delay in delivering oxygen in the scalpel–finger–bougie arm compared with the scalpel–finger–cannula arm consistently exceeded this threshold, for both consultant and registrar participants. Similarly, the delay in delivering oxygen with registrars compared with consultants frequently exceeded this threshold in the scalpel–finger–bougie arm. In contrast, although the impact of registrar grade was present in the scalpel–finger–cannula arm, it appeared to be of diminished clinical significance (consistently less than 30 s).

In addition to the clinically important consequences of delayed oxygen delivery, there was a high outright failure rate with scalpel–finger–bougie (37%). Rees and colleagues[9] reported a similar overall scalpel–bougie failure rate (35%), and commented that significant tissue trauma during 11 of the 15 failed first attempts made any subsequent success unlikely. We also found first attempt failure with a scalpel–finger–bougie approach (43%) markedly increased the likelihood of subsequent failure (86%). This suggests that repeated attempts at scalpel-based approaches have a low yield. Conversely, Rees and colleagues[9] reported a very low

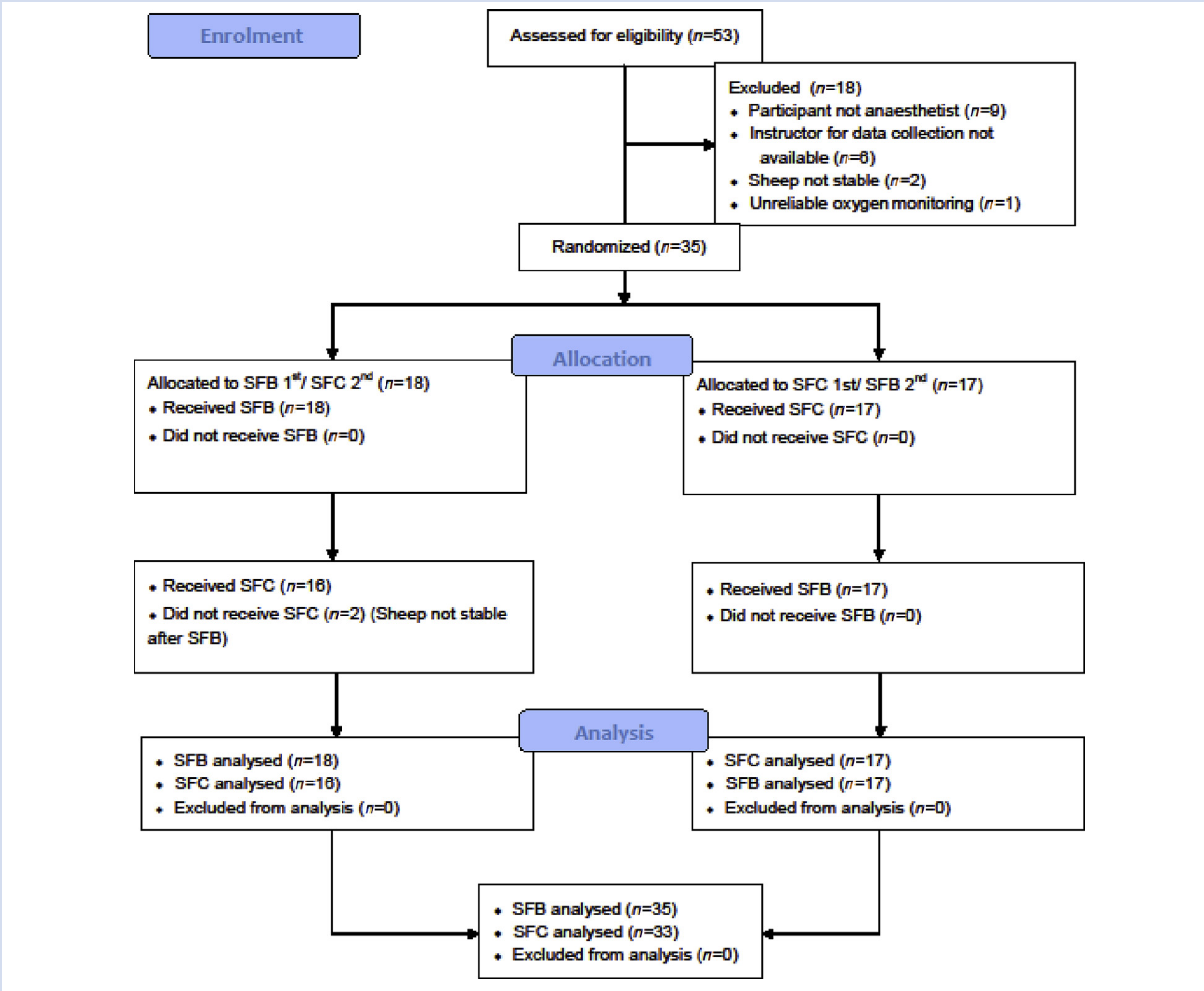

Fig 2. Consort diagram for data collection. SFB, scalpel–finger–bougie; SFC, scalpel–finger–cannula.

number of failures with cannula-based rescue (2%), which was equivalent on first (19%) and second (13%) attempts. Scalpel–finger–cannula failure in the present study was similarly very low overall (3%), and equivalent on first (18%) and second attempts (17%). These findings together lend credence to a 'cannula-first' approach to CICO rescue, where in the rare event of cannula failure, the minimally invasive nature of the technique allows for meaningful repeat attempts or escalation to more invasive, scalpel-based procedures.

There are several potential explanations for the differences observed in time to oxygen delivery and overall success. Firstly, the feedback obtained on successful tracheal puncture is substantially different with each technique. For scalpel–finger–cannula, aspiration of air is a clear and objective endpoint that retains value even when the palpated trachea is obscured by bleeding. In contrast, the stab incision and scalpel rotation at the outset of scalpel–finger–bougie relies heavily on airway visualisation, and clear feedback of failed tracheal puncture (too superficial, too deep, non-tracheal structure palpated) is often delayed to when difficulty inserting or advancing the bougie is encountered. Secondly, when tracheal puncture is adequate, correct alignment of the bougie during insertion can be obstructed by adjacent soft tissue,[10] and the risk of para-tracheal insertion increases. Indeed, our data show that high levels of confidence during scalpel–finger–bougie at the point of tracheal puncture did not translate into an equivalent rate of successful oxygen delivery. However, all the participants who were confident *after* bougie insertion achieved subsequent oxygen delivery on the same attempt. Finally, the improved performance exhibited by consultant participants across both techniques may reflect a more practiced, composed approach to the challenges of bleeding and restricted manoeuvrability.

In contrast to our results, a review by Duggan and colleagues[11] reported a high rate of device failure (42%) and barotrauma (32%) with cannula-based or narrow-bore rescue approaches across 90 clinical CICO emergencies. The low rate of cannula failure and absence of barotrauma events in the present study likely reflects the immediate availability of appropriate equipment, highly specific training on cannula selection, insertion, and troubleshooting, and adoption of safe jet oxygenation strategies using a purpose-designed device,

Table 1 Cox proportional hazards model for primary outcome. CI, confidence interval; CICO, can't intubate, can't oxygenate.

Variable	Univariate		Multivariate	
	Hazard ratio	95% CI	Hazard ratio	95% CI
Scalpel–finger–cannula *vs* scalpel–finger–bougie (baseline)	11.37	25.13–5.14	8.87	4.31–18.18
Consultant *vs* Registrar (baseline)	2.22	1.28–3.86	3.28	1.36–7.95
Previous Royal Perth Hospital Wet lab training	2.09	1.19–3.70		
Years since last CICO training	1.045	0.873–1.252		
Cranial *vs* caudal impalpable section	0.792	0.460–1.364		

the Rapid-O_2®. The presence or absence of these influential factors could not be discerned in the studies reviewed by Duggan and colleagues.[11] However, the authors' analysis of 42 non-CICO emergencies, in which operator performance and equipment availability are presumed superior to the CICO setting, revealed much lower rates of device failure (0%) and barotrauma (7%). Overall, these findings support the 2015 Difficult Airway Society guidelines[4] that recognise the validity of cannula-based approaches in hospitals where additional equipment and comprehensive training programmes are available, and clinicians are experienced in their use. Such programmes are established in many parts of Australia,[12] and in some parts of the USA,[13] Canada,[14] and the UK.[15]

Our study outcomes were not universally favourable for scalpel–finger–cannula. In particular, the time to a cuffed airway and first capnography reading when comparing successful attempts only, was one and a half minutes longer with scalpel–finger–cannula. This is not surprising given that Royal Perth Hospital CICO teaching has long advocated for the supremacy of oxygenation over ventilation ('CICO' rather than 'CICV'). The wet lab algorithm advises a minimum 30 s of oxygenation and stabilisation after successful cannula insertion, whilst considering whether to awaken the patient (not applicable after vertical neck dissection), attempt further upper airway techniques or perform a Seldinger conversion to a cuffed Melker 5.0 airway. This approach can facilitate success with conventional upper airway techniques, as human factors and equipment availability improve, and transforms the Melker conversion process into a controlled, minimally traumatic procedure taking approximately 60 s. The prolongation of time to first capnography in the current study is thus consistent with these steps. Nevertheless, it represents a clinically important period in which airway protection and capnography measurement will be superior with a successful scalpel–finger–bougie approach. However, it is our belief that this advantage is offset by the longer time to first oxygen delivery, longer time to SpO_2 improvement, and the considerable overall failure rate discussed above.

The study design had strengths and weaknesses. One strength was the application of a time-to-event analysis for the primary outcome that retained the influence of rescue procedures that ultimately failed; information that is lost if time to first oxygen delivery is only considered in successful participants. We also evaluated the relative merits of CICO

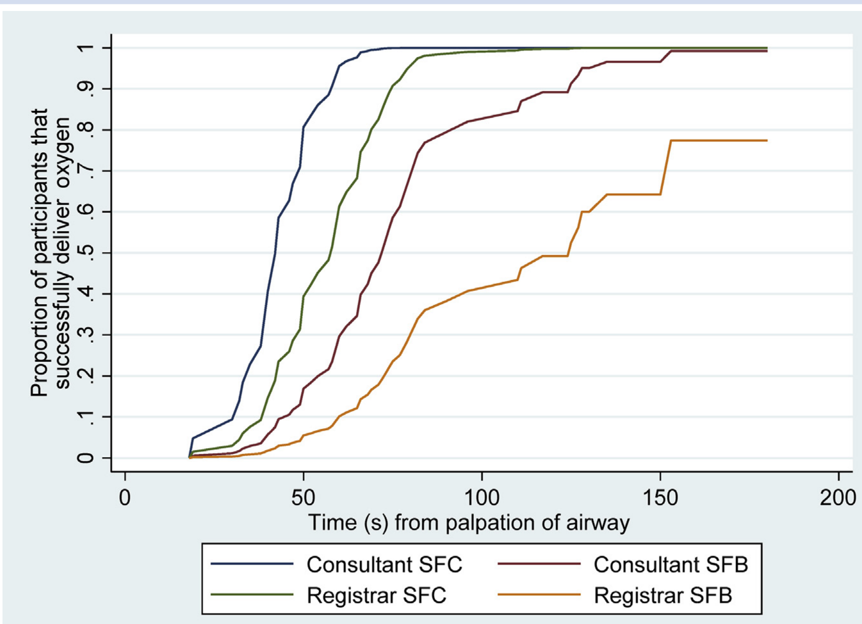

Fig 3. Multivariable Cox proportional hazards model for primary outcome. SFB, scalpel–finger–bougie; SFC, scalpel–finger–cannula.

Table 2 Secondary outcomes in scalpel–finger–bougie and scalpel–finger–cannula arms. Times are presented as median (Q1–Q3) and are from declaration of a CICO scenario in successful participants only. *Fourteen participants had a second attempt at scalpel–finger–bougie; six participants had a second attempt at scalpel–finger–cannula. CICO, can't intubate, can't oxygenate.

	Scalpel–finger–cannula (n=33)	Scalpel–finger–bougie (n=35)
Success during first attempt, n (%)	27 (82)	20 (57)
Success during second attempt, n (%)*	5 (83)	2 (14)
Overall success, n (%)	32 (97)	22 (63)
Time to palpation of trachea (s)	38 (30–52)	38 (32–44)
Time to oxygen delivery (s)	96 (80–133)	113 (100–127)
Time to improvement in SpO_2 (s)	118 (107–154)	135 (126–146)
Time to first capnography (s)	215 (179–253)	119 (108–140)

rescue techniques when performed by experienced anaesthetists, with nearly all declaring previous formal CICO training. Finally, several strategies to minimise bias were used including rigorous pre-course and dry lab preparation for both techniques; exposure to the same number of bougie- and cannula-based procedures on the palpable sheep airway before data collection; a randomised procedure sequence on the impalpable sheep airway after minimum tracheal depth confirmed; and elimination from the primary outcome analysis of any inter-individual variation in performing the midline vertical incision.

A significant weakness was the use of infused fluid in a restricted space to create an impalpable neck. Although this effectively generates tracheal depths in excess of 30 mm at baseline, the midline vertical incision required at the outset of both rescue procedures can result in rapid leakage of infused fluid and a superficial trachea during cannula or scalpel attempts. At present, we have not identified a better method of simulating impalpable sheep anatomy in the wet lab. A further weakness was demarcation of the impalpable neck into two 7 cm sections. The Difficult Airway Society describes an 8–10 cm midline vertical incision followed by blunt tissue dissection. The choice of 7 cm was dictated by the limited length of a sheep neck, and the recognition that neck length can also be restricted in humans with difficult airways. Major vessels also frequently overlie the trachea at the level of the suprasternal notch (and up to 3 cm cranially),[16] and where this is seen at CICO onset a shorter vertical incision is indicated. Finally, we did not explicitly record whether prior CICO training had covered the scalpel–finger–cannula or scalpel–finger–bougie techniques, and imbalance in prior exposure remains a potential source of bias. However, cannula and scalpel–bougie techniques are taught with equal emphasis across Western Australia when airway anatomy is palpable, reflecting our sequential approach to airway rescue. Both the Difficult Airway Society and our own guidelines describe the wholesale application of palpable techniques, with no refinement or adjustment, when the airway is initially impalpable, but becomes palpable after a vertical neck incision with finger dissection. Thus, the impact of prior exposure to impalpable rescue techniques should be minimal.

Importantly, neither this study nor the one conducted by Rees and colleagues[9] evaluated CICO rescue techniques at the cricothyroid membrane, the area exclusively targeted by the Difficult Airway Society guidelines. Success rates with both scalpel–bougie and cannula approaches are indeed much higher in this zone in the wet lab, where airway anatomy is more easily palpated and relatively fixed. However, inaccuracy identifying the cricothyroid membrane is well described.[17] In a systematic survey of anaesthetists that had experienced a clinical CICO event (n=281), a third reported being unable to palpate the cricothyroid membrane at any stage, leading to a three-fold increase in mortality.[18] This difficulty identifying the cricothyroid membrane was a major influence over the development of our cannula-first approach, which targets the most palpable part of the airway at any given time, and avoids delays that arise from fixation on palpating the cricothyroid membrane only. We are not aware of any data detailing rates of successful palpation of the cricothyroid membrane *after* vertical neck incision with finger dissection in high-fidelity models, and we can only speculate that difficulties observed in healthy volunteer studies would continue in the presence of bleeding and heightened operator stress. Future studies could address this whilst comparing oxygen delivery performance between a cannula approach targeting any airway structure and a bougie approach targeting the cricothyroid membrane only. However, high-fidelity impalpable anatomy models are very difficult to create in the cricothyroid region and we have been unable to achieve this in our wet lab. Despite these significant unknowns, scalpel–finger–cannula still appears to improve oxygen delivery performance in the most difficult of CICO scenarios, when the trachea only is available for puncture. Teaching this

Table 3 Participant confidence and oxygen delivery success during first attempt.

	Scalpel–finger–cannula (n=33)		Scalpel–finger–bougie (n=35)	
	Confident	Success when confident	Confident	Success when confident
Identifying trachea, n (%)	31 (94)	26 (84)	33 (94)	20 (61)
Puncturing trachea, n (%)	25 (76)	23 (92)	28 (80)	18 (64)
Inserting bougie or check aspiration, n (%)	24 (73)	23 (96)	15 (43)	15 (100)

technique may therefore maximise the likelihood of a favourable outcome across the full spectrum of CICO difficulty.

In conclusion, we are cognisant that there are limitations to anaesthetised animal models of simulated CICO scenarios that prevent direct extrapolation of study findings to clinical practice, including differences in tracheal anatomy and an absence of all the human factors that influence performance in a real-world crisis.[19,20] Nonetheless, such models remain the closest experimental approximation possible, and are complementary to clinical case reports and registries that are in turn, vulnerable to reporting bias and incomplete data. In this context, we have replicated and added to the study by Rees and colleagues,[9] demonstrating that oxygen delivery during high-fidelity CICO scenario simulation with impalpable airway anatomy is faster and less likely to fail with a scalpel—finger—cannula approach.

Authors' contributions

Study design: AH, HG, NG, HA, AT
Data collection: AH, HG, SD, NG, HA
Data analysis: SD, PV, AT
First draft of manuscript: AT
Revision of manuscript: AH, HG, SD, NG, HA, PV

Declaration of interest

PV has no conflicts of interests. All the remaining authors have taught, presented or published on CICO rescue techniques. Many CICO courses we have been involved in have received training equipment from Cook, VBM, and Meditech. AH has received funds from sales of his eBook, which have been used to support CICO courses.

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Appendix B. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.bja.2020.04.067.

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