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Respiration and the Airway

Rabbit training model for establishing an emergency front of neck airway in children

Christian P. Both[1,2], Birgit Diem[1], Elena Alonso[1,3], Michael Kemper[1,4], Markus Weiss[1,2], Alexander R. Schmidt[2,5], Markus Deisenberg[1] and Jörg Thomas[1,2,*]

[1]Department of Anaesthesiology, University Children's Hospital Zurich, Zurich, Switzerland, [2]Children's Research Centre, University Children's Hospital Zurich, Zurich, Switzerland, [3]Department of Anaesthesiology, University Hospital Zurich, Zurich, Switzerland, [4]Department of Anaesthesiology, University Hospital Aachen, Aachen, Germany and [5]Department of Anaesthesiology, Perioperative and Pain Medicine, Stanford University, School of Medicine, Palo Alto, CA, USA

*Corresponding author. E-mail: joerg.thomas@kispi.uzh.ch

Abstract

Background: A 'cannot intubate, cannot oxygenate' (CICO) situation is rare in paediatric anaesthesia, but can always occur in children under certain emergency situations. There is a paucity of literature on specific procedures for securing an emergency invasive airway in children younger than 6 yr. A modified emergency front of neck access (eFONA) technique using a rabbit cadaver model was developed to teach invasive airway protection in a CICO situation in children.

Methods: After watching an instructional video of our eFONA technique (tracheotomy, intubation with Frova catheter over which a tracheal tube is inserted), 29 anaesthesiologists performed two separate attempts on rabbit cadavers. The primary outcome was the success rate and the performance time overall and in subgroups of trained and untrained participants.

Results: The overall success rate across 58 tracheotomies was 95% and the median performance time was 67 s (95% confidence interval [CI], 56–76). Performance time decreased from the first to the second attempt from 72 s (95% CI, 57–81) to 61 s (95% CI, 50–81). Performance time was 59 s (95% CI, 49–79) for untrained participants and 72 s (95% CI, 62–81) for trained participants. Clinical experience and age of the participants was not correlated with performance time, whereas the length of the tracheotomy incision showed a significant correlation (P=0.006).

Conclusion: This eFONA training model for children facilitates rapid skill acquisition under realistic anatomical conditions to perform an emergency invasive airway in children younger than 2 yr.

Keywords: bougie; cannot intubate, cannot oxygenate; emergency front of neck airway; emergency tracheotomy; paediatric airway; rabbit cadaver model

Editor's key points

- Although difficulty in airway management after induction of anaesthesia is rare in children, a 'cannot intubate, cannot oxygenate' (CICO) situation can still occur.
- A rabbit model is effective for training for emergency front of neck access (eFONA) technique in children.

In paediatric anaesthesia, the incidence of an unexpected difficult airway is rare in the hands of a well-trained paediatric anaesthetist.[1] Accordingly, a 'cannot intubate, cannot

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oxygenate' (CICO) situation should not occur in a child with a normal airway when airway management is performed in accordance with appropriate professional standards.[1–3]

Nevertheless, a CICO situation can occur in children at any time under certain emergency situations and is often associated with a poor outcome.[4,5] Examples include anaphylactic shock or other clinical scenarios with massive acute swelling of laryngeal or pharyngeal tissues (such as repeated traumatic intubation attempts) or severe facial trauma.[5–7] Published reports show that in a CICO situation, a lack of training and the absence of appropriate material for securing an invasive airway can lead to a detrimental delay in establishing airway access.[8,9] It is also known that the execution of an emergency front of neck access (eFONA) in a small child is a considerable challenge for a physician who is not trained in paediatric ear–nose–throat (ENT) surgery because of the extreme rarity of a CICO event and because of the small airway structures. Training models should therefore be as realistic and the technique as simple as possible to increase the chance of successfully performing an eFONA in a small child.

Which eFONA technique is the most reliable in a CICO situation in small children is still under debate.[10–12] The puncture technique for small children was formerly favoured by paediatric anaesthesiologists[13] but has increasingly been scrutinised in recent years as the overall failure rate was high (57%) in comparison with surgical eFONA (88%) across various animal models.[12,14–16] An infant's anatomy, with a short neck and a relatively high positioned larynx just below the level of the chin, requires a steep puncture of the small and compressible trachea, which bears together for a high risk of perforating the posterior tracheal wall and thus a malposition of the cannula.[11,15] The needle technique has also become increasingly questioned in adults[14] and the current Difficult Airway Society (DAS) Guidelines 2015 for adults consider a surgical cricothyrotomy to be the most reliable method.[17,18] In infants and toddlers, the dimensions of the cricothyroid membrane is too small to even insert the smallest tracheal tube.[19,20] In addition, because of the anatomical dimensions of the infant's and toddler's neck, an accurate and reliable identification of the location of the cricothyroid membrane is difficult.[21] Accordingly, surgical tracheotomy is a suitable invasive emergency airway technique in this age group. In this study, the feasibility and applicability of a modified eFONA technique (emergency tracheotomy) using a rabbit model was evaluated by investigating the success rate, the performance time, and serious adverse outcomes.

Methods

After approval by the Ethics Committee Zurich (Req-2020-00111) and ClinicalTrial.gov registration (NCT04573790), 29 anaesthesiologists (23 senior physicians, six fellows) were included in this study. Separated from the other study participants, each participant had the opportunity to perform two tracheotomies. Only one person from the study team assisted the study participants. For each tracheotomy, a fresh rabbit cadaver was prepared and disposed duly after the procedure. Immediately preceding the procedure, each participant watched an instructional video for the adapted emergency tracheotomy (Fig. 1 online video).

Rabbit cadaver model

Zimmermann rabbits aged 80–90 days with a live weight of 2.5–3.5 kg were used for this study. The head and neck preparation of the rabbits used in the model are slaughterhouse waste and were purchased from the slaughterhouse H.R. Kyburz Vieh + Fleisch AG (Aargau, Switzerland). The rabbits had been slaughtered for food and non-scientific purposes in accordance with Swiss law.

First, the head and neck area of the rabbit is shaved and then the rabbit's head is placed into the head of a baby mannequin (ALS Baby Head, Laerdal®; Laerdal Medical Corp., Myers Corner, NY, USA) (Fig. 1a and b). In order to achieve maximum possible hyperextension of the cervical spine, as in a real-life emergency scenario, and to improve access to the

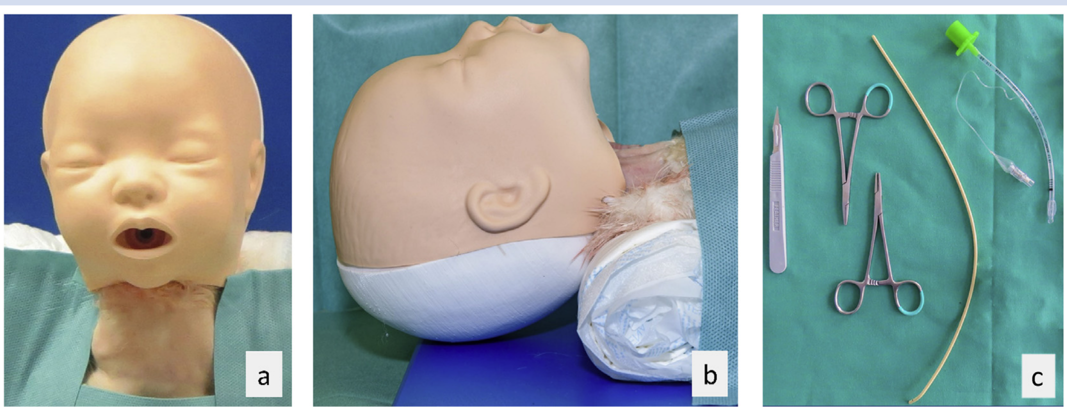

Fig 1. (a) The head of the rabbit is placed in a mannequin baby head (ALS Baby Head, Laerdal®) in order to simulate the anatomical conditions as realistically as possible. The position of the lower jaw in relation to the axis of the airway in the infant or toddler is of particular importance. (b) A shoulder roll (approximately 8 cm) induces hyperextension in the cervical spine and the cadaver is fixed on a board by tying down the otherwise forward-facing forelegs. This allows free access to the trachea and additional stabilisation of the rabbit on the board. (c) For the modified emergency front of neck access (eFONA) technique in this study, the following materials were used: an 11-blade scalpel, two preparation clamps, an 8 Fr Frova catheter and a cuffed tracheal tube with an inner diameter of 3 mm.

target structures, a cloth roll is positioned under the upper half of the rabbit's thorax (Fig. 1b). In addition, the ventrally oriented paws are fixed latero-dorsally on a rigid board to keep the lateral access to the cervical structures free and to additionally stabilise the rabbit in a supine position.

Tracheotomy set materials

The eFONA surgical tracheotomy set for infants and young children used in our anaesthesia department is summarised in Supplementary Table S1. The exact same set is used in our regular training workshops at our institution. For comparability of the results in this study, only the 3.0 mm inner diameter (ID) cuffed tracheal tube was used (Fig. 1c).

Procedure

Our modified eFONA technique requires two trained providers. Ideally, a right-handed executor will sit on the right side of the training model and *vice versa* for left-handed executer on the left side to palpate the laryngeal structures (Fig. 2a). The assistant sits with one preparation clamp in each hand at the head end of the table. Then the executor performs a sufficiently long (3 cm) longitudinal skin incision from the larynx in a caudal direction with an 11-blade scalpel (Fig. 2a). The assistant uses the clamps to grasp the skin and to pull the skin incision apart in a dorso-lateral direction (Fig. 2b). Next, the individual anatomical layers are cut through and alternately grasped with the clamps and pulled apart as required (Fig. 2c). As soon as the trachea is seen, it is opened by approximately 5–7 mm (two to three tracheal rings) with a longitudinal incision (Fig. 2d). A Frova catheter (8 French) is then inserted through the tracheal opening and advanced caudally (Fig. 2e). In theory, initial oxygenation is now possible via the 8 Fr Frova catheter, with a device such as the Ventrain®,[22] especially in cases where the definite airway device is difficult to place. With the Frova catheter in the trachea, a cuffed tracheal tube with an ID of 3.0 mm can then be inserted over the catheter for final securing of the airway and ventilation of the lungs (Fig. 2f).

Outcome measures

The performance time was measured from the first skin incision until the tracheal tube was placed into the trachea. Successful completion of the modified eFONA technique was defined as the correct insertion of a tracheal tube into the trachea within 240 s. A performance time of greater than 240 s or a paratracheal placement of the tracheal tube was defined as failure.[14,15]

Serious secondary injuries were defined as a paratracheal placement of the tracheal tube and a perforation of the back wall or a complete rupture of the trachea. After each emergency tracheotomy, the trachea including larynx was carefully

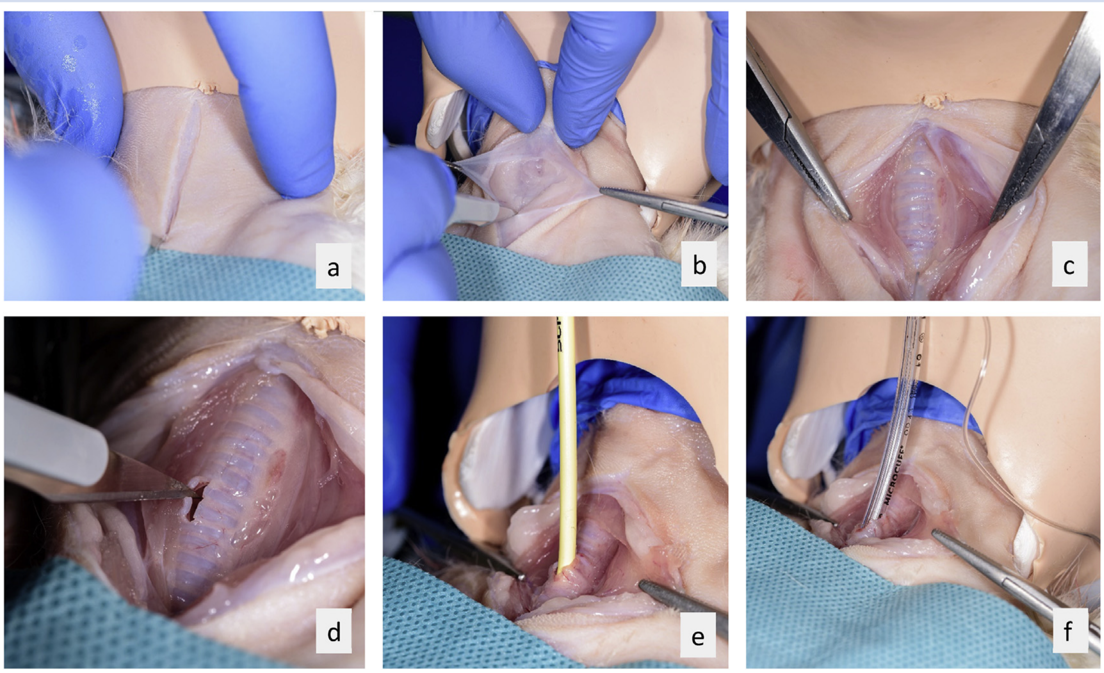

Fig 2. (a) The assistant places themselves with two preparation clamps at the head end of the table and assists with each hand placed lateral to the neck, so that the operating field is freely accessible for the executor. After the trachea or cricoid is palpated by the surgeon, a sufficiently long median longitudinal skin incision of 2–3 cm is made from the cricoid caudally. (b) The assistant uses straight clamps to pull the two edges of the skin incision apart dorso-laterally. Theoretically, in the event of major bleeding this manoeuvre should allow the blood to drain off dorsally and the view of the anatomical structures should be less impaired. (c) Layer by layer of the anatomical structures are cut through with the scalpel and tightened with the clamps accordingly. (d) Using a longitudinal incision, two to three tracheal rings are cut through distally to the cricoid, thus opening the trachea 5–7 mm. (e) An 8 Fr Frova catheter is inserted through the orifice into the distal trachea. (f) A tracheal tube (inner diameter 3.0 mm, cuffed) is inserted over the Frova catheter to secure the airway permanently.

retrieved from the rabbit cadaver, and the following parameters were measured: external lateral tracheal diameter directly under the tracheotomy, length of the tracheotomy, and distance of the tracheotomy from the cricoid cartilage and thyroid cartilage. Each trachea was opened lengthwise to evaluate for tracheal back wall perforations. Assessment for secondary tracheal injuries and the parameter measurements noted above were performed independently by two study investigators. The mean of the measured parameters was then calculated and used for further analysis.

Statistical analysis

The primary outcomes were the success rate and the performance time across a first and a second attempt with the model. In subsequent subgroup analyses, the performance time and success rates were stratified for different subgroups (13 trained *vs* 16 untrained) for comparison. Untrained participants had never taken part in our institutional eFONA workshop and the trained participants completed our eFONA workshop within 6 months before participating in this study. The study population of 29 participants was defined in order to allow for identification of a difference of at least 20 s between subgroups with a power of 80% and a one-sided type I error rate of 0.05. For the power analysis, the performance time in the untrained group was estimated at 67.3 s in concordance with recent data on cannula techniques.[12,15] The time difference of 20 s was chosen in concordance with akin studies.[15]

Analyses for parametric and non-parametric data were performed using the Shapiro–Wilk test. Descriptive statistics with differences between groups are shown as mean with standard deviation (SD) for parametric data and as median with 95% confidence interval (95% CI) for non-parametric data. Data were compiled in Microsoft Excel 2013 (Microsoft Corporation, Redmond, WA, USA) and processed using Prism 9 (GraphPad Software Inc., La Jolla, CA, USA) for statistical analysis. Mann–Whitney tests were performed for statistical significance for non-parametric data and χ^2 test was used to analyse differences between sex/clinical position in the subgroups, with $P<0.05$ considered to be statistically significant. Pearson and Spearman correlation coefficients were calculated between performance time and length of tracheotomy, age, and clinical experience of participants.

Results

Sixteen untrained and 13 trained participants performed a total of 58 emergency tracheotomies in a modified rabbit cadaver tracheotomy model. There were no significant differences in sex distribution, age, and clinical experience between trained and untrained participants (Supplementary Table S2).

The mean (SD) lateral outer tracheal diameter was 7.7 (0.9) mm. The median tracheostomy length was 4.4 mm (95% confidence interval [95% CI], 4–5.4) and median distances from the cricoid and thyroid cartilages were 3.8 mm (95% CI, 0–6) and 11 mm (95% CI, 10–11.4), respectively (Fig. 3).

The overall success rate of emergency tracheotomy was 95% (three failures). The overall median performance time was 67 s (95% CI, 56–76) and decreased from the first to second attempt from 72 s (95% CI, 57–81) to 61 s (95% CI, 50–81) (P=0.31; Fig. 4). Severe secondary injuries were found in five of 58 rabbit cadavers (9%), including two perforations of the tracheal back wall, two complete tracheal ruptures, and one paratracheal placement of the tracheal tube.

In the subgroup analysis, the performance time was overall shorter in the untrained group compared with the trained group without reaching a significant difference (59 s [95% CI, 49–79] *vs* 72 s [95% CI, 62–81]; P=0.23). The success rate was 92% in the trained group and 96% in the untrained group.

There was no correlation between performance time and participant age or years of clinical experience (Fig. 5a and b). The length of the tracheotomy was the only variable found to significantly correlate with the performance time (Fig. 5c).

Discussion

This study shows the feasibility of our modified eFONA technique with respect to success rate and performance time in a rabbit model. In comparison with other eFONA models for children, the presented technique demonstrates a high success rate with only few secondary injuries.[12,14,15,23–25]

With the approach of inserting the rabbit head into a baby mannequin, the anatomical conditions of an infant neck is replicated to a realistic standard. For example, the position of the lower jaw in relation to the airway axis in this model corresponds well to anatomical conditions in the infant. In this study, the lateral outer diameter of the rabbit trachea correlates with the size of a child's trachea around the age of 0–2 yr.[26] The size of a piglet trachea (8–10 kg) used by Johansen and colleagues[14] corresponds more closely with the size of a child's trachea between 4 and 6 yr of age.[26,27] Therefore, the presented rabbit model seems to be the currently best available animal model for training eFONA in paediatric patients under the age of 6 and especially for the first 2 yr of life.[28]

Our emergency tracheotomy model for children is based on the eFONA piglet model by Johansen and colleagues[14] and the rabbit model of Ulmer and colleagues.[23] There are

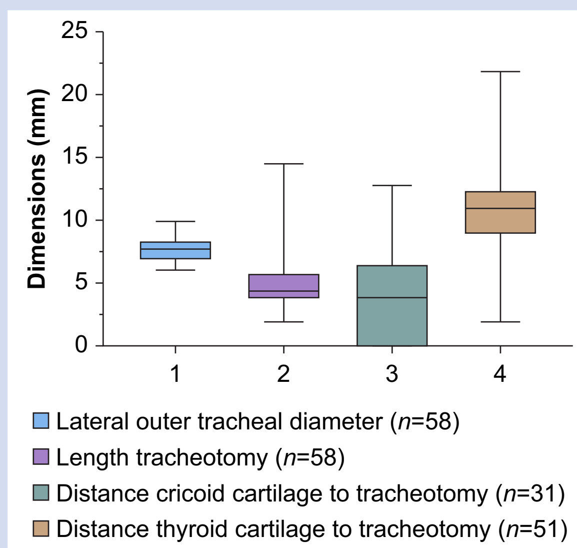

Fig 3. Anatomical dimensions of the rabbit trachea and length and distances of the tracheotomy from the cricoid or thyroid cartilage. The box plots represent median, lower and upper quartiles with minimal and maximal whiskers.

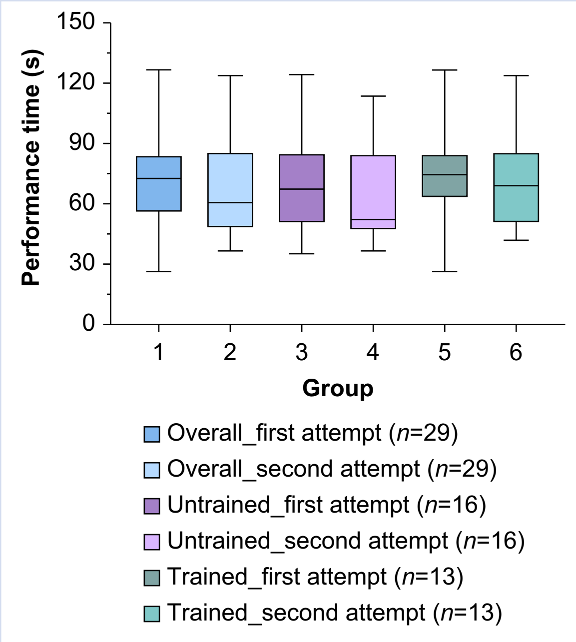

Fig 4. Performance time overall, in the first and second attempt and in subgroup of trained *vs* untrained participants. The box plots represent median, lower and upper quartile with minimal and maximal whiskers.

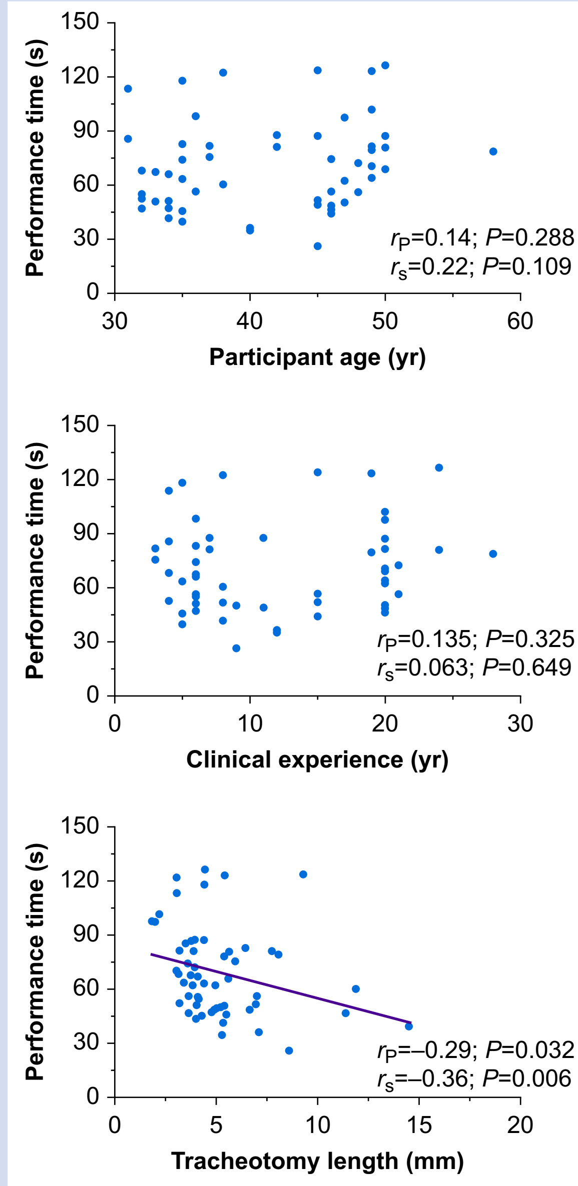

Fig 5. Correlation between performance time and (a) age of participants, (b) clinical experience of participants, and (c) tracheotomy length. Only tracheotomy length correlates significantly with performance time. r_P, Pearson correlation coefficient; r_s, Spearman correlation coefficient.

nevertheless a number of important differences to consider. Both approaches propose lifting up the trachea from cranial with a tissue clamp and then opening it with scissors lengthwise right below the cricoid.[14,23] Considering the anatomical conditions of an infant (larynx located right beneath the chin), it is probably more difficult to lift and open the trachea starting cranially in this age group than it is in piglets or rabbits. In the former scenario, the human chin compromises the path to the surgical field, so that the surgical equipment can only be used at a steep angle. It is also conceivable that with the 'lift' of the trachea, serious secondary injuries may occur more frequently.[29] This is in accordance with the study of Ulmer and colleagues,[23] who demonstrated severe secondary injuries in 54% of cases during the first attempt and in 10% even after the 10th attempt during emergency tracheotomy in their model.

One explanation for the low rate of secondary injuries in our model may be the use of a Frova catheter to initially secure the surgically opened airway instead of a primary tracheal tube. A thin 8 Fr (2.7 mm) Frova catheter allows easier probing of the just-opened tracheal lumen, a gentler advancement into the distal trachea and better tactile assessment of resistance than with a 3.0 mm ID tracheal tube. This approach is also favoured by other authors and the DAS, as the tracheal tube can be inserted more gently and easily with rotating movements while the tracheal orifice remains secured.[11,17] The emergency tracheotomy set for neonates/infants published by Sabato and Long[11] also contains bougies of different sizes for initial securing of the airway. The authors also highlight the easier insertion of the tracheal tube and the possibility of initial oxygenation via the 8 Fr Frova catheter, such as with a Ventrain® device.[22] However, the authors critically note that a 3.0 mm ID cuffed tracheal tube is relatively difficult to insert over the 8 Fr Frova catheter and therefore a dislocation of the tracheal tube may occur when the Frova catheter is withdrawn/removed. We recognised the same problem in our study with some of the cuffed ID 3.0 mm tracheal tube used. Alternatively, an uncuffed 3.5 mm ID tracheal tube could be used, which has the disadvantage of a larger outer diameter and thus a greater calibre jump between the tube and Frova catheter. Further studies are planned to investigate the applicability of an uncuffed 3.5 tracheal tube or neonatal 3.0 tracheal cannula in our eFONA animal model.

We further demonstrated that the performance time significantly correlates with the length of the tracheotomy incision (Fig. 5c). Heard and colleagues[30] also showed that a short incision significantly prolongs the performance time in an adult surgical cricothyroidectomy model with the use of the bougie technique. A tracheotomy length of 5 mm should be long enough to allow for a fast and less traumatic insertion of a cuffed 3.0 mm ID tracheal tube.

Using the tracheotomy technique by Johansen and colleagues[14] or Ulmer and colleagues,[23] the overall success rate was 80% in the piglet and 94% in the rabbit model, respectively. After 10 training attempts the mean performance time in the rabbit model was under 55 s. In our model the overall success rate and the median performance time in the second attempt are comparable with results by Ulmer and colleagues[23] at their 10th attempt. One could argue that our study included previously trained participants. However, between trained and untrained participants the performance time was not significantly different.

Taken together, the high success rate, short performance time, and comparatively low number of secondary injuries at the first attempt[12,14,23] highlight the learnability and simplicity of our rabbit model eFONA technique.

This study also carries several limitations. It is nearly impossible to make a statement about the applicability of our modified eFONA approach to a real CICO situation in young children. Furthermore, the mental stress of an unanticipated CICO situation cannot be simulated in a workshop. Moreover, the assistant role was always performed by the same person, which makes it even more difficult to interpret the performance time for a real CICO situation with random combination of two health care providers.

As with any cadaver model, the proposed surgical access route for invasive airway management does not take into account the risk of bleeding.[31] It is known, however, that bleeding during emergency or elective tracheotomy is one of the leading complications, often with fatal outcomes.[32,33] A remedy for this problem could be to integrate the simulation of bleeding tissue into an artificial training model as described by Hughes and colleagues[34] or to use live animals under anaesthesia.[35] However, this would result in either a step back towards the use of artificial eFONA models, which only reflect real conditions to a limited extent, or in the case of using live animals, an enormous organisational effort, which is difficult to implement for a regular eFONA training. Therefore, we have started to combine our rabbit eFONA model with an artificial bleeding source. Future studies will have to investigate the influence of this important complication on the performance time in this eFONA model.

One aim of this study was to evaluate if training has an impact on the performance time. Therefore, we compared if participation in an eFONA workshops 6 months before this study would have an impact on the performance time. Surprisingly, we did not see a significant effect on the performance time. Using a cadaver model with anatomical variance from animal to animal rather than a standardised artificial eFONA model might explain why no significant differences were found. Furthermore, viewing the training film just before the workshop may have a significant impact on the performance of eFONA and thereby levelling potential differences between the two subgroups. This issue requires further investigation, which is planned for future studies.

In summary, the presented technique for eFONA in a rabbit model represents a promising and realistic scenario for the training of eFONA in infants and young children. In contrast to previously published techniques, the tracheal tube is inserted via a primarily inserted Frova catheter, which seems to be a relevant factor for greater success and fewer injuries and thus leads to increased safety. Regular training of our suggested model, and the provision and rapid availability of the necessary materials are elementary prerequisites for being able to act quickly and successfully in a CICO situation. Further prospective and randomised studies are necessary to investigate the impact of regular training on the performance time, success rate, and secondary injuries in this model.

Authors' contributions

Study design: JT, CPB, BD
Data collection: CPB, JT, EA, MK, BD, MD
Data analysis/interpretation: JT, CPB, ARS, MW
Writing first draft of manuscript: JT, CPB
Critically revising the manuscript: all authors.

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Declarations of interest

The authors declare that they have no conflicts of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.bja.2020.12.032.

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