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Newborn face mask ventilation training using a standardised intervention and respiratory function monitor: a before and after manikin study

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ABSTRACT

Objective The International Liaison Committee on Resuscitation has recommended improvements in training for neonatal resuscitation, highlighting the potential role of respiratory function monitors (RFMs). Our objective was to determine whether a manikin-based, standardised face mask ventilation training intervention using an RFM with a simple visual display reduced face mask leak.
Design Multicentre, before and after study. Participants and instructors were blinded to the RFM display during both assessment periods.
Participants Healthcare professionals working or training in a hospital providing maternity and neonatal services.
Intervention All participants underwent a training intervention on positive pressure ventilation using a modified, leak-free manikin and RFM. The intervention consisted of a demonstration of optimal face mask ventilation technique, training in RFM interpretation with corrective strategies for common scenarios and a period of deliberate practice. Each participant performed 30s of positive pressure ventilation blinded to the RFM display before and after training.
Main outcome measures The primary outcome was face mask leak (%) measured after training. Secondary outcome measures included expired tidal volume, inflating pressures and ventilation rate. Adjustments made to technique during training were an important qualitative outcome.
Results Four hundred and fourteen participants were recruited over a 13-month period from April 2022, and 412 underwent analysis. Median (IQR) face mask leak before training was 31% (10–69%) compared with 10% (6–18%) after training (p<0.0001). Improvements were noted across all other ventilation parameters.
Conclusion Standardised face mask ventilation training using an RFM with simple visual feedback led to a significant reduction in leak.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Respiratory function monitors provide feedback on tidal volume, mask leak, inflating pressures and respiratory rate during face mask ventilation but can be difficult to interpret.
⇒ Previous studies have focused on using these devices to identify and reduce mask leak without developing standardised training strategies to improve technique.

WHAT THIS STUDY ADDS

⇒ Using a respiratory function monitor with a simple visual display, we developed a training intervention that equips the learner with strategies to identify and correct suboptimal technique.
⇒ Participation in this standardised intervention led to improved face mask ventilation in a national cohort of healthcare professionals.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ This is a short, effective and easily reproducible training intervention in an area where poor mask ventilation is common and can have significant clinical sequelae.

BACKGROUND

Learning how to provide positive pressure ventilation (PPV) is a critical component of neonatal resuscitation training. Effective PPV is difficult to perform and can be complicated by high, variable mask leak[1–5] and airway obstruction.[1 6] PPV is usually taught using a manikin and manual ventilation device (eg T-piece device) guided by the visual estimation of adequate chest excursion which even experienced neonatal practitioners find challenging.[7] Current strategies to optimise PPV as outlined by guidelines on newborn resuscitation include a series of adjustments focused on mask, head and jaw position, suctioning, opening the airway and increasing inflation pressure,[8] summarised by the 'MRSOPA' acronym.[9] Feedback and active experimentation using a respiratory function monitor (RFM) has been shown to improve the effectiveness of face mask ventilation, leading to an overall reduction in leak during skills training.[10]

An RFM provides continuous, quantitative data on tidal volume (Vt), leak, inflating pressures and ventilation rate allowing for assessment of the operator's mask ventilation technique, supplementing subjective visual assessments with objective measurements. It offers the potential for individualised instructor feedback which is informed by the visual display of ventilation parameters. There are, however, limitations to using RFMs in training. Challenges interpreting the feedback from monitors have been reported,[11] which may lead to incorrect management.[12] Furthermore, there is a paucity of validated corrective strategies for use during training to address ineffective ventilations. The aim of this study was to determine whether a short,

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standardised training intervention on face mask ventilation using an RFM with a simple visual display reduced face mask leak in a group of healthcare professionals caring for newborns.

METHODS

Study design

This was a multicentre, before and after manikin study.

Participants and instructors

Healthcare professionals (midwives, nurses, doctors, students; midwifery, nursing and medical) working or training in a hospital providing maternity and neonatal services (non-tertiary and tertiary) were eligible for participation. Prospective, written informed consent was obtained from all participants. The training intervention was conducted by two instructors (CMNC, neonatal fellow and LS, advanced nurse practitioner).

Equipment

We modified a Laerdal Resusci Baby manikin by inserting a 50 mL test lung (Dräger, Lubeck, Germany) into the chest cavity to create a leak-free system. A Monivent NeoTraining RFM (Gothenburg, Sweden) measured airflow and gas pressure using a flow restrictor and differential pressure sensor. The flow restrictor was placed between a T-piece resuscitator (Neopuff) and face mask and attached to the pressure sensor module via a Luer-Lock connection, with a combined weight of 19 g. The air flow to and from the manikin during ventilation flows over the flow restrictor leading to a flow-dependent pressure drop. The sensor module measures this pressure difference and converts it to a flow signal to calculate the Vt in mL. Inflating and deflating ('expiratory') volumes are recorded by the device; however, it is the expiratory Vt (Vt_e) in mL/kg that is displayed on the monitor during PPV. The difference between inflating and deflating Vt is used to calculate mask leak, which is expressed as a percentage of the inflating volume. Data are transmitted wirelessly to an external tablet device (iPad, Apple, Cupertino, California, USA) which displays continuous visual feedback on mask leak (%), Vt_e (mL/kg), ventilation rate (per minute), peak inspiratory pressure (PIP) and positive end-expiratory pressure (PEEP) in cmH_2O, recording the parameters for future analysis. Inflation pressures, percentage leak and ventilation rate are displayed numerically while Vt_e is displayed both numerically and graphically. In the graphic feedback, Vt_e assumes the shape of a cylinder that fills, empties and changes to one of three colours depending on the measured volume: low (red), within target range (green) or high (orange). A light-emitting diode (LED) light located at the tip of the sensor module changes colour to reflect the Vt_e.

A simulated manikin weight of 3 kg and target Vt_e of 4–8 mL/kg were inputted into the RFM, consistent with previous studies.[13] Inflation breaths were delivered with a T-piece (Neopuff Infant Resuscitator, Fisher & Paykel Healthcare, Auckland, New Zealand) with a target ventilation rate of 40–60 inflations/min. Settings were fixed at a gas flow of 10 L/min, PIP of 20 cmH_2O and PEEP of 5 cmH_2O in line with local resuscitation guidelines.[9] The face mask used for term infant resuscitation at each participating centre was used. Prior to training, the instructors familiarised themselves with the face mask using feedback from the RFM to identify the optimal mask hold.

Outcome measures

The primary outcome was mean face mask leak (%) during mask ventilation performed immediately after the training intervention. A comparison was made between the values before and after training. Secondary outcomes included Vt_e, PIP, PEEP, ventilation rate and adjustments made to the participant's technique during deliberate practice. We chose mean face mask leak after training as the primary outcome as it is both objective and measurable in a manikin. Although Vt_e was an important secondary outcome, it is affected by multiple factors such as lung compliance and airway resistance which are not readily replicated in a manikin.

Intervention

Participants were trained in situ in the clinical area most relevant to their daily practice (eg, delivery room for midwives, neonatal unit for neonatal nurses), in groups of two to three within the same professional group. Two instructors participated in each training session, one facilitated training (instructor) while the other recorded data and addressed any technological issues that arose. All participants underwent a standardised training intervention on PPV. In summary, this consisted of an instructor-led demonstration of optimal face mask ventilation technique, RFM interpretation and a period of deliberate practice with individualised feedback. An overview of the intervention as it was delivered in real time is outlined in figure 1 and described in detail below.

Face mask ventilation instruction consisted of a standardised description and manikin-based demonstration on how to optimise PPV technique focusing on airway position, face mask placement and holds, pressure and jaw lift as outlined by Wood *et al*.[5] Visual aids depicting a variety of face mask holds were distributed and attention was drawn to the whistling sound emitted from the PEEP valve of the T-piece with adequate mask seal. RFM instruction began with a standardised description of the device's utility and function followed by training on interpretation of its visual display. Picture cards illustrating the display during optimal ventilation, high leak, excessive Vt_e and airway obstruction were circulated and corrective strategies to redress these common scenarios were outlined and demonstrated. Participants then proceeded to a period of deliberate practice which is a highly structured activity whereby a discrete training objective is identified and the learner performs the same task repeatedly with continuous feedback, as described by Ericsson.[14] Feedback from the RFM allows the learner to make self-corrections to improve the quality of the ventilations. Participants were tasked with the goal of achieving or maintaining a Vt_e of 4–8 mL/kg and mask leak <30% during PPV, in line with other published studies.[2 4 13–16]

If the participant's leak was >30% after a period of deliberate practice with self-correction, the instructor made adjustments to their technique by following a stepwise, standardised algorithm (figure 1). Adjustments were limited to one at a time. If inflations remained suboptimal (leak >30%), the training intervention was repeated. Each participant received individualised feedback after the intervention.

Blinded assessment

There were two distinct periods of blinded assessment: before and immediately after the training intervention during which time the participant performed 30 s of uninterrupted PPV without instruction. Both participant and instructor were blinded to the visual display on the RFM and to the coloured LED light at the tip on the sensor module during assessment periods. The tablet was removed from the resuscitaire and covered to conceal the visual display once an instructor had confirmed air flow

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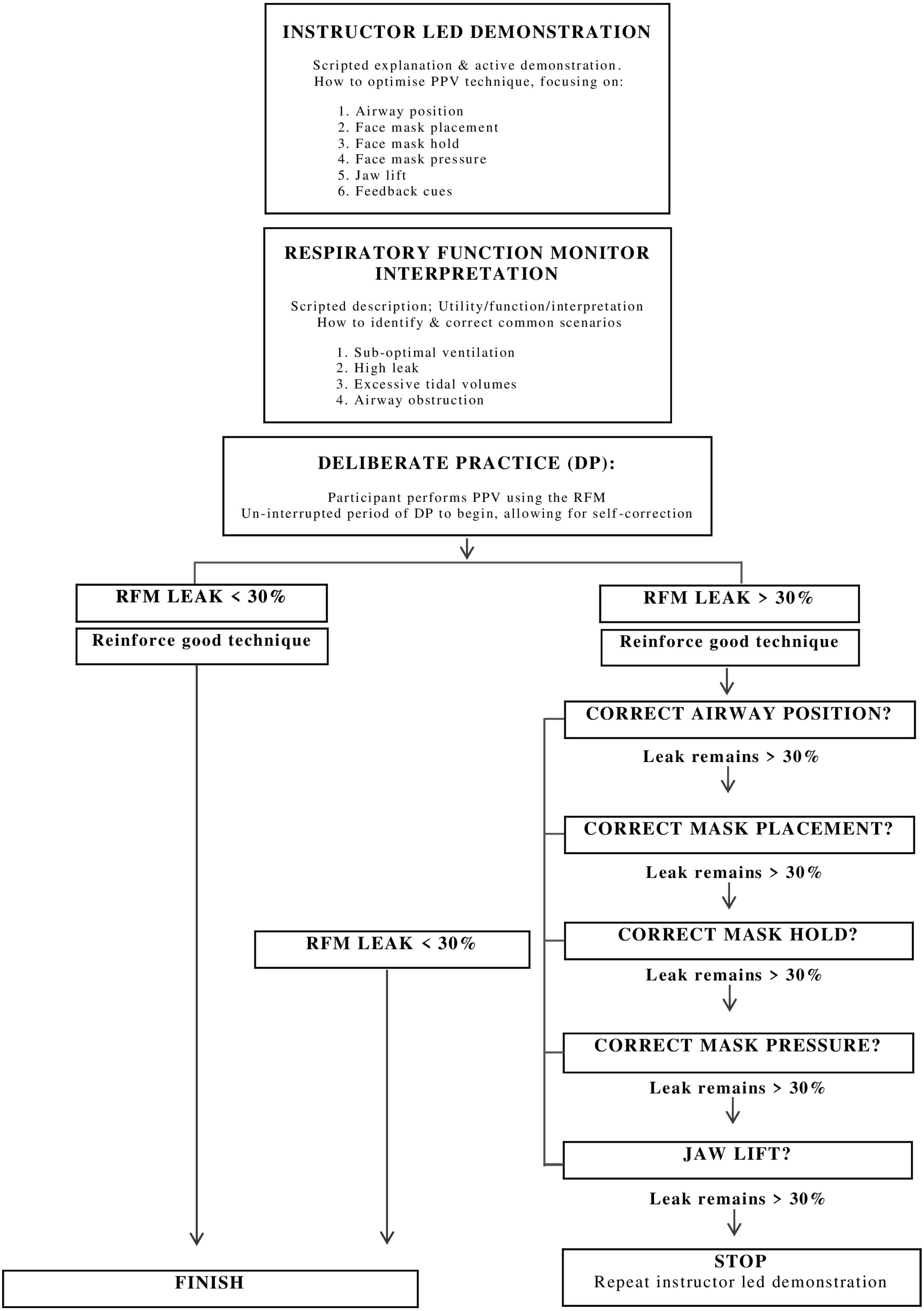

Figure 1 Flow diagram: training algorithm. PPV, positive pressure ventilation; RFM, respiratory function monitor.

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Table 1 Participant characteristics

Characteristic	Detail	n=412
Professional role, n (%)	Midwife	128 (31)
	Nurse*	104 (25)
	Doctor	134 (33)
	Student/other†	46 (11)
Sex, n (%)	Female	337 (82)
Workplace, n (%)	Paediatrician-led inpatient care	306 (74)
	Neonatologist-led inpatient care	106 (26)
Experience in newborn care (years), median (IQR)‡		4 (1–14)
<2 years since completion of newborn resuscitation training programme (which includes PPV), n (%)		299 (73)

*Neonatal, paediatric or theatre nurse.
†Midwifery, paediatric nursing or medical student/allied health professionals.
‡n=340.
PPV, positive pressure ventilation.

detection after the first inflation. Brown opaque tape was used to conceal the coloured light on the sensor module.

Statistical analysis

We aimed to train healthcare professionals from two-thirds of all hospitals providing neonatal care nationally and to achieve a minimum convenience sample size of 400. Continuous data are presented as mean (SD) when normally distributed and median (IQR) when skewed. Outcome variables were analysed using the Student's t-test for parametric comparison and Mann-Whitney U test for non-parametric comparison of continuous variables. Data were clustered by participant. P values are two sided and p values of less than 0.05 were considered statistically significant. Data were analysed using Stata software (StataCorp, V.18, College Station, Texas, USA).

RESULTS

From April 2022 to May 2023, we recruited 414 participants from 13 of 19 (68%) hospitals providing neonatal care in Ireland. All participants consented prospectively to inclusion. Two participants were excluded as their outcome assessment was not saved due to human error. Participants (n=412) were made up of 128 (31%) midwives, 104 (25%) nurses, 134 (33%) doctors and 46 (11%) students/others. We conducted the intervention in a variety of clinical settings including delivery wards, operating theatres, postnatal wards, special care baby units and neonatal intensive care units. Demographic characteristics of participants are outlined in table 1. The median (IQR) leak before training was 31% (10–69%) compared with 10% (6–18%) after training ($p<0.0001$; figure 2). A reduction in leak was noted across all healthcare professional groups (table 2). The mean (SD) Vt_e was lower before training (15.3 mL (5.7)) versus after training (19.0 mL (2.6)), ($p<0.0001$). Differences in means (SD) were noted across all other ventilation variables including improvement in ventilation rate (39 (11) before vs 45 (6) after, $p<0.0001$), PIP (18.7 (1.7) before vs 19.3 (0.7) after, $p<0.0001$) and PEEP (4.3 (0.8) before vs 4.8 (0.6) after, $p<0.0001$) (table 2). Participants engaged in deliberate practice for a median (IQR) time of 97 (65–155) s. Adjustments made to the participant's technique through self-correction and/or by the instructor are outlined in figure 3. Overall, 358 of 412 (87%) participants made adjustments. Within this group, adjustments made to the anatomical placement of the mask and/or to the downward pressure exerted through the mask, in isolation, made up over one-quarter of all modifications to technique.

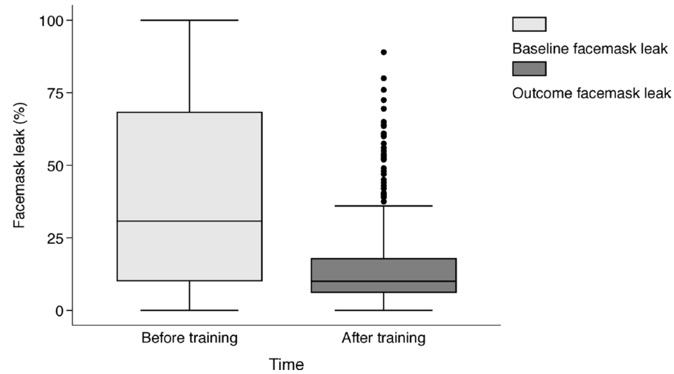

Figure 2 Comparison of leak (%) before and after training. Participants and instructors blinded to the RFM display. The horizontal line in each box represents the median, the top and bottom of the box represent the IQR and the whiskers represent the adjacent values (most extreme values within 1.5 IQR of the nearest quartile). Circles plotted beyond the whiskers represent outliers. RFM, respiratory function monitor.

DISCUSSION

Participation in a short, manikin-based training intervention using an RFM with a simple visual display led to a reduction in face mask leak and improvement in all other ventilation parameters in a large group of healthcare professionals. The range of leak observed after training was narrower and centred more closely around the median, suggesting more consistent delivery of Vt and an improvement in participants with high leak. To date, the visual feedback from RFMs has required considerable instruction, time and experience to interpret, as highlighted by

Table 2 Comparison of respiratory function monitor outcome data before and after training

Outcome	Before n=412	After n=412	P value
Leak (%), median (IQR), overall	31 (10–69)	10 (6–18)	<0.0001
Leak (%), median (IQR), by professional group			
Midwife*	39 (12–72)	10 (7–17)	
Nurse†	34 (10–73)	10 (5–17)	
Doctor‡	19 (9–65)	10 (6–17)	
Student/other§	29 (10–65)	14 (9–24)	
Expiratory Vt (mL), mean (SD), overall	15.3 (5.7)	19.0 (2.6)	<0.0001
Expiratory Vt (mL), mean (SD), by professional group			
Midwife*	15.1 (5.9)	19.2 (2.4)	
Nurse†	14.6 (6.1)	19.0 (3.1)	
Doctor‡	16.1 (5.1)	18.8 (2.5)	
Student/other§	15.0 (6.1)	18.6 (2.3)	
PIP (cmH_2O), mean (SD)	18.7 (1.7)	19.3 (0.7)	<0.0001
PEEP (cmH_2O), mean (SD)	4.3 (0.8)	4.8 (0.6)	<0.0001
Ventilation rate (inflations/min), mean (SD)	39 (11)	45 (6)	<0.0001

*n=128.
†n=104.
‡n=134.
§n=46.
PEEP, positive end-expiratory pressure; PIP, peak inspiratory pressure; Vt, tidal volume.

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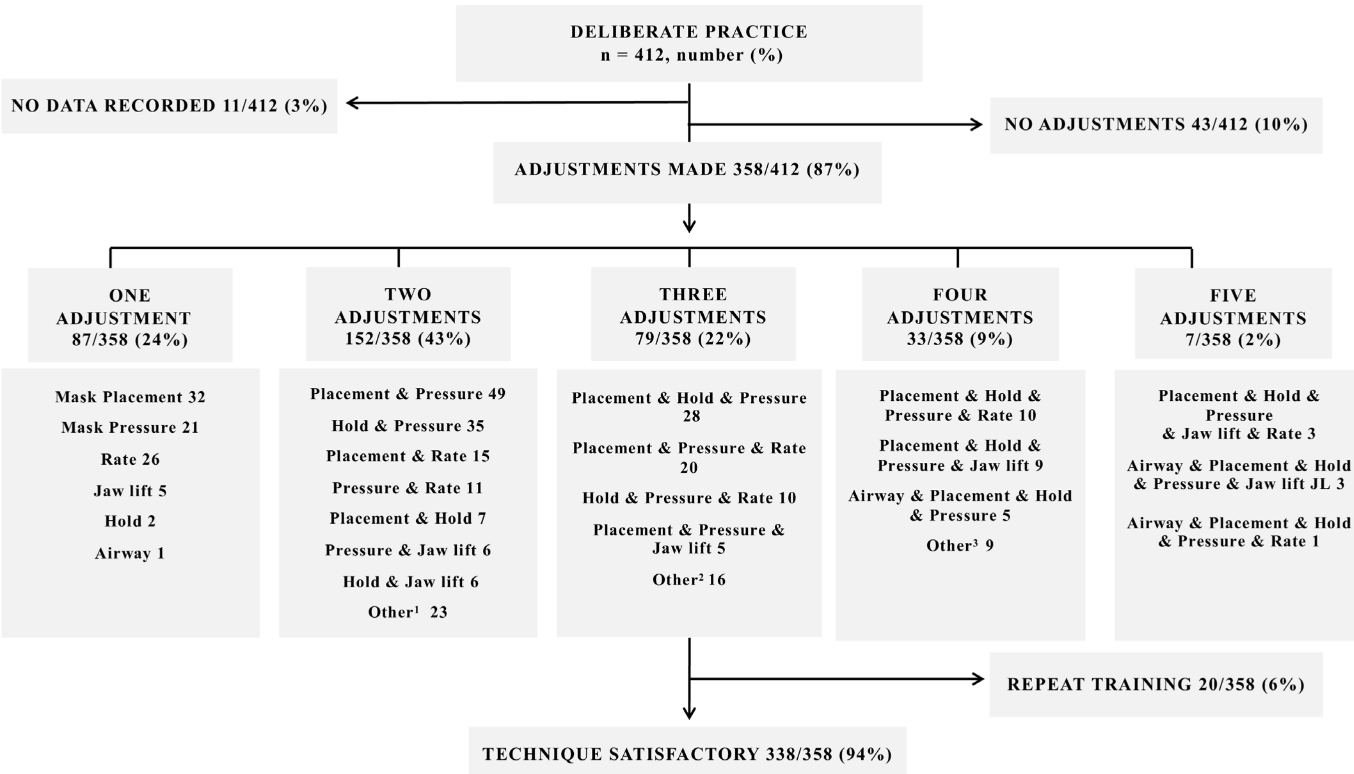

Figure 3 Adjustments made during deliberate practice by self-correction and/or instructor. [1]Hold & Rate 5, Placement & Jaw lift 4, Jaw lift & Rate 4, Airway & Pressure 3, Airway & Placement 3, Airway & Hold 2, Airway & Jaw lift 1, Airway & Rate 1. [2]Airway & Placement & Pressure 4, Placement & Hold & Rate 4, Hold & Pressure & Jaw lift 4, Airway & Placement & Rate 1, Airway & Hold & Jaw lift 1, Placement & Hold & Rate 1, Pressure & Jaw lift & Rate 1. [3]Airway & Pressure & Jaw lift & Rate 2, Placement & Pressure & Jaw lift & Rate 2, Hold & Pressure & Jaw lift & Rate 3, Airway & Placement & Pressure & Jaw lift 1, Placement & Hold & Jaw lift & Rate 1.

incorrect management strategies with inexperienced users.[12] Kuypers *et al*[11] emphasised the need for improved training on RFM interpretation after surveying resuscitators involved in the MONitoR trial,[15] suggesting that a simpler visual interface may facilitate interpretation, a sentiment echoed by Schilleman *et al*.[17] In response to this, we chose an RFM with a user-friendly interface. The simplicity of the Monivent's colour-coded visual display, which adopts a traffic light system to depict Vt_e, requires minimal training to interpret, as demonstrated by the short (approximately 3 min) training section on monitor interpretation.

Feedback devices have been reported to facilitate adult learning,[14] where engagement in practice with informative, objective feedback is linked with improved performance. Previous manikin and delivery room studies have focused on using RFM's to identify mask leak and improve technique without developing training strategies to correct suboptimal inflations in response to the visual feedback.[10 15] We developed a standardised training intervention to address this. The structure of the intervention integrates contemporary teaching methodologies and research, incorporating evidence-informed content, deliberate practice and feedback.[18–20] The intervention is short, reproducible and effective in reducing mask leak in the immediate phase thereafter. The brevity of the intervention may lend itself well to ongoing training.

The majority of participants made adjustments to their technique during the intervention. Adjustments to the anatomical placement of the mask and/or to pressure constituted 25% of all changes. We hypothesise that when rolling the mask on to the manikin's face from the direction of the chin, the operator may be primarily focused on ensuring that the mouth is encircled by the mask. Although this is the method of mask placement recommended in formal training programmes,[9] it may lead to mask misplacement too low on the face. Additionally, we noted that downward pressure from the index finger and thumb was frequently imbalanced, directed mostly through the index finger towards the chin. Both of these actions can lead to air leak from around the contour of the nose, an area highly susceptible to leak. The whistling sound emitted from the PEEP valve of the T-piece with adequate mask seal was a useful feedback cue that numerous participants were unaware of prior to training. Many thought this sound was from leak around the mask. This simple feedback cue is both important and useful and may be worthwhile mentioning during resuscitation training.

This study has important limitations. First, the observed reduction in mask leak may not translate into clinical practice where resuscitators are faced with challenges such as infant movement, spontaneous breathing and additional monitoring devices, all of which may affect the delivery of effective ventilations and add to cognitive overload.[21] Second, as the standardised training intervention was integrated with RFM feedback and other feedback cues, we could not assess them separately in a randomised fashion. Finally, it has been widely reported that resuscitation skills wane over time,[22 23] with deterioration of skills likely as early as 3 months following training.[24] We did not perform a follow-up evaluation to assess whether participants' skillset deteriorated over time, a limitation to the study that warrants investigation. A strength of the study is the enrolment of healthcare professionals across all hospital levels with diverse clinical roles and varying amounts of experience. This adds to the generalisability of the results. Furthermore, the development

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of a standardised training algorithm designed as a blueprint for instructors may add to its reproducibility outside of the research environment.

CONCLUSIONS

This study has demonstrated that a manikin-based, standardised face mask ventilation training intervention using an RFM with simple feedback was associated with an improvement in face mask ventilation competency. This study addresses the need for training on the use and interpretation of RFMs for neonatal resuscitation teaching.[25] Studies examining the introduction of periodical, standardised, educational interventions such as this are warranted to assess whether practitioners improve and maintain their skillset in the absence of frequent clinical exposure.

Correction notice Since this article was first published the licence for this paper has been changed to Open Access.

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Contributors All authors have actively contributed. CMNC conceptualised and designed the study, delivered the training intervention, collected and analysed data, wrote the first draft of the manuscript and critically reviewed and revised the manuscript. LS collected the data, delivered the training intervention and reviewed and revised the manuscript. AEC and EO'C conceptualised and designed the study, supervised the project and reviewed and revised the manuscript. EO'C performed data analysis and interpretation and is the guarantor. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

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Competing interests None declared.

Patient consent for publication Not required.

Ethics approval This study involves human participants and was approved by the Ethics Committee of the National Maternity Hospital, Dublin, Ireland (ethics approval reference number: EC24.2021). Participants gave informed consent to participate in the study before taking part.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement All data relevant to the study are included in the article or uploaded as supplemental information.

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