Innovations in Cardiorespiratory Monitoring to Improve Resuscitation With Helping Babies Breathe

Jackie K. Patterson, MD, MPH,[a] Sakina Girnary, MSE,[b] Krysten North, MD, MPH,[a] Santorino Data, MBChB, MMed,[c] Daniel Ishoso, MD,[d] Joar Eilevstjønn, PhD,[b] Carl L. Bose, MD[a]

abstract

Ninety percent of intrapartum-related neonatal deaths are attributable to respiratory depression, with the vast majority of these deaths occurring in low- and lower-middle–income countries. Neonatal resuscitation training with Helping Babies Breathe (HBB) decreases mortality from respiratory depression. Cardiorespiratory monitoring in conjunction with HBB can provide valuable resuscitation feedback for both training and bedside purposes. In this article, we discuss 3 innovations that couple cardiorespiratory monitoring with HBB: NeoNatalie Live, the Augmented Infant Resuscitator, and NeoBeat. NeoNatalie Live is a high-fidelity manikin that facilitates bag mask ventilation training through case scenarios of varying difficulty. The Augmented Infant Resuscitator is added in-line between a face mask and ventilation bag during bag mask ventilation training to provide users with real-time feedback on ventilation quality. NeoBeat is a battery-operated heart rate meter that digitally displays the newborn heart rate during bedside resuscitations. For each innovation, we review details of the device, implementation in the field, and areas for further research. Using early experience implementing these devices, we suggest building blocks for effective translation of training into improved care. We also highlight general challenges in implementation of devices in facilities in low- and lower-middle–income countries including considerations for training, adaptations to existing workflow, and integration into the ecosystem. Although the devices highlighted in this article hold promise, more data are needed to understand their impact on newborn outcomes.

[a]Department of Pediatrics, School of Medicine, University of North Carolina, Chapel Hill, North Carolina; [b]Laerdal Medical, Stavanger, Norway; [c]Mbarara University of Science and Technology, Mbarara, Uganda; and [d]Kinshasa School of Public Health, University of Kinshasa, Kinshasa, Democratic Republic of the Congo

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Address correspondence to Jackie K. Patterson, MD, MPH, Division of Neonatal-Perinatal Medicine, University of North Carolina Hospitals, 101 Manning Dr, 4th Floor, Room N45051, Campus Box 7596, Chapel Hill, NC 27599-7596. E-mail: jackie_patterson@med.unc.edu

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One million newborns die on their day of birth each year, accounting for one-third of all newborn deaths.[1,2] Ninety percent of these deaths are from respiratory depression, defined as failure to breathe at birth.[3] Nearly all of these deaths occur in low- and lower-middle–income countries (LMICs).[1] Training in basic resuscitation practices with Helping Babies Breathe (HBB) reduces mortality from respiratory depression.[4–7] However, knowledge and skill decline after training, and gaps in the quality of resuscitation persist.[8,9] A variety of complementary strategies have been paired with HBB training to sustain and enhance reductions in mortality.

In the past 5 years, investigators have explored cardiorespiratory monitoring as a strategy to improve newborn resuscitation in conjunction with HBB. This strategy is a recommended part of the resuscitation algorithm in high-income countries (HICs), with cardiorespiratory data supporting both training and bedside resuscitations. For example, resuscitation training in HICs typically includes practice with a high-fidelity manikin that automatically simulates both heart rate and breathing.[10] Similarly, providers in HICs use cardiorespiratory data from the newborn acquired via electrocardiogram (ECG) and pulse oximetry to guide bedside resuscitation. The challenge in adopting this strategy in LMICs is to develop not only effective but also practical methods of cardiorespiratory monitoring.

In this article, we highlight 3 innovations that have been paired with HBB to deliver cardiorespiratory data to improve newborn resuscitation: (1) post hoc feedback on ventilation quality during simulation with NeoNatalie Live, (2) real-time feedback on ventilation quality with the Augmented Infant Resuscitator (AIR), and (3) continuous heart rate monitoring during bedside resuscitation with NeoBeat. Because all 3 of these devices are relatively new, we cite published articles as well as gray literature, both obtained through searches of PubMed, Scopus, Embase, trial registries, and Google, as well as personal communication with the device developers. For each innovation, we review details of the device, implementation in the field, and areas for further research.

NEONATALIE LIVE: HIGH-FIDELITY SIMULATION FOR VENTILATION TRAINING

Background

Implementation of HBB has demonstrated that complex skills such as bag mask ventilation (BMV) require ongoing practice to achieve mastery.[9,11] This practice is traditionally supported by a low-fidelity manikin called NeoNatalie. Developed by Laerdal Global Health, NeoNatalie can be inflated with air or filled with lukewarm water for realistic size and appearance and is sold for use in LMICs at US $62.[12] Participants of HBB courses are encouraged to use NeoNatalie for quick and frequent practice of BMV at their facility, a strategy commonly referred to as low-dose high-frequency (LDHF) training.

Although LDHF training improves maintenance of knowledge and skill, adherence is challenging. Successful adoption of LDHF training requires individual provider motivation, practice in pairs to facilitate feedback, and coordination of training sessions. These elements can be burdensome in LMIC settings. Understaffed clinical environments can reduce provider time and motivation to practice BMV and make practice in pairs challenging to accomplish. Additionally, in-facility coordinators tasked with scheduling, facilitating and tracking practice sessions may not have time or resources to devote to this task. Adherence to LDHF training may be improved through strategies that reduce the burden of adoption.

Device Description

NeoNatalie Live is Laerdal Global Health's second-generation newborn simulator for low-resource settings (Fig 1).[13] Although the shape and size of NeoNatalie Live is similar to its predecessor, it is not inflatable; rather, it comes prefilled with dry pellets for compatibility with the electronics inside. Designed to support more engaging, relevant, and effective LDHF training, the manikin can simulate a variety of lung transitions after birth through a valve that controls the openness of the airway and an ECG generator that provides heart rate responding to lung aeration. The manikin also detects head positioning for opening the airway, mask seal, air pressure delivered to the lungs, ventilation rate, and continuity of ventilation. Finally, NeoNatalie Live features an infant cry sound to indicate spontaneous breathing at the end of a successful resuscitation.

Through a tablet-based application, a provider can practice $<$5-minute case scenarios that vary in difficulty on the basis of the initial heart rate and lung compliance of the manikin (Fig 2). These case scenarios are built on data from ~1200 actual newborn resuscitations, ensuring that training emulates the real-life challenges providers commonly face. Integrated with Bluetooth, the manikin displays a heart rate during simulation. The tablet application displays performance-based objective feedback after a practice session. NeoNatalie Live may reduce the burden of LDHF training through high-fidelity simulation that motivates providers, objective feedback that allows for solo practice, and automatic data capture to decrease the work of a coordinator.

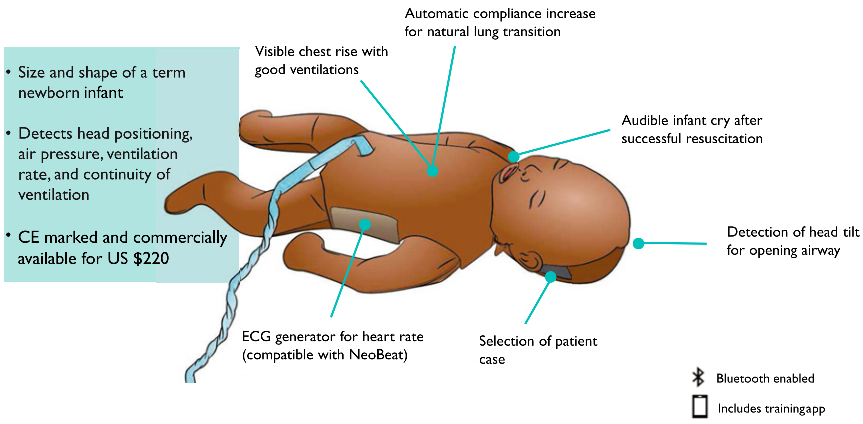

FIGURE 1
Technical illustration highlighting key features of NeoNatalie Live. CE, certified in the European Economic Area to meet health, safety and environmental protection standards.

Implementation in the Field

NeoNatalie Live has been evaluated in one observational cohort study with nurses in Nepal.[14] In this study, authors evaluated both adequacy of ventilation (defined as ventilating with a rate of 40–60 breaths per minute) and effectiveness of ventilation (defined as feedback of "well done" from the manikin) with 47 nurses. Participants trained in HBB engaged in 3 months of intermittent skill drills using NeoNatalie Live. Adequate ventilation was not correlated with the number of skill drills (*P* = .88) nor the difficulty level of the skill drill (*P* = .28). Effective ventilation was achieved in at least 1 skill drill by 74.5% of participants. Of note, 55% of participants did not attend births, and 38% had never used a bag and mask, thus limiting the generalizability of this study.

The effect of NeoNatalie Live on resuscitation training, BMV performance, and newborn outcomes is under study through additional implementation efforts. A stepped-wedge cluster randomized controlled trial in Nepalese hospitals recently completed enrollment to evaluate NeoNatalie Live with HBB as part of a larger quality improvement package to reduce intrapartum-related mortality (http://isrctn.org [identifier ISRCTN16741720]).[15] Eight hospitals, each with at least 3000 deliveries per year, participated. Results from this trial are forthcoming. Aside from Nepal, NeoNatalie Live is also being used in facilities in Hungary, India, Kenya, Nigeria, Norway, Slovakia, Tanzania, and the United States. Since August 2016, at least 471 learners have completed at least 230 000 sessions with NeoNatalie Live (internal data from Laerdal Global Health).

FIGURE 2
Features of NeoNatalie Live for use during ventilation training.

Areas for Further Research

Importantly, it remains unclear whether high-fidelity simulation is more effective in maintaining and/or improving knowledge and skills compared to low-fidelity simulation.[16] As such, the International Liaison Committee on Resuscitation (ILCOR) suggests the use of high-fidelity manikins when infrastructure, trained personnel, and resources exist to maintain the program (weak recommendation based on very low-quality evidence).[17] Further research should consider the relative efficacy of BMV skills acquisition with NeoNatalie Live compared to low-fidelity NeoNatalie.

Participant preference for high-fidelity manikins is well documented in HICs and may impact motivation to train.[17] High-fidelity simulation with automatic feedback may help providers both become engaged (finding a reason to start training) and remain engaged (finding a reason to continue) as they discover improvement in their skills with practice. Given the potential impact on motivation to train, programs should seek to understand adherence to LDHF training comparing the two high- and low-fidelity simulators.

As with all training strategies to improve newborn resuscitation care, future studies should be used to address the effectiveness of simulation training on bedside resuscitation practices, morbidity, and mortality. Hybrid research designs that also explore key implementation outcomes such as feasibility and cost-effectiveness should be prioritized.

THE AUGMENTED INFANT RESUSCITATOR (AIR): REAL-TIME FEEDBACK FOR VENTILATION TRAINING

Background

BMV is a critical step in neonatal resuscitation in the HBB algorithm.[18] Even with appropriate training and practice, BMV may be technically difficult and prone to error.[19,20] Furthermore, multiple factors contribute to ineffective ventilation, most commonly airway blockage and face mask leak. HBB recommends providers evaluate the effectiveness of BMV using the neonate's chest rise. In the absence of chest rise, HBB recommends corrective steps to improve BMV including repositioning the head, clearing the mouth and nose of secretions, and opening the mouth (all targeting airway blockage) as well as reapplying the mask (targeting face mask leak). If these measures are ineffective, a provider can perform the fifth corrective step of increasing pressure by squeezing the bag harder.

Delayed recognition of inadequate ventilation can delay corrective steps. Although practical for LMICs, chest rise is a less-sensitive marker of effective ventilation compared to heart rate. Automated strategies to detect ineffective ventilation could improve rapid use of corrective steps, resulting in earlier, more effective ventilation. Furthermore, automated strategies that identify the cause of ineffective ventilation could prompt quicker selection of the appropriate corrective step.

Device Description

The AIR is added in-line between a face mask and ventilation bag to evaluate the quality of BMV (Fig 3). The device was created by a team from the Massachusetts Institute of Technology, Massachusetts General Hospital, and Uganda's Mbarara University of Science and Technology. The AIR senses airflow, pressure, and volume and subsequently fits these data to a system impedance model to provide real-time feedback on face mask seal, airway patency, and rate of ventilation.[21,22] In addition to real-time feedback on ventilation quality parameters, the AIR device logs time-stamped performance data for quality improvement. Logged data include the total ventilation time, time and duration of effective ventilation, duration with a good face mask seal, and duration with a patent airway. Of note, the AIR imposes only marginal air-path resistance, similar to a 5.0-mm endotracheal tube. In validation testing of the fourth-generation prototype, the AIR was 100% accurate in determining face mask leaks and airway obstruction.[22]

The AIR device uses color-coded digital iconography to communicate the state of ventilation quality (Fig 4). Effective ventilation is achieved when the AIR device lights green at the face mask, airway, and ventilation rate icons.

The AIR may enable health providers to achieve effective ventilation sooner, retain effective ventilation

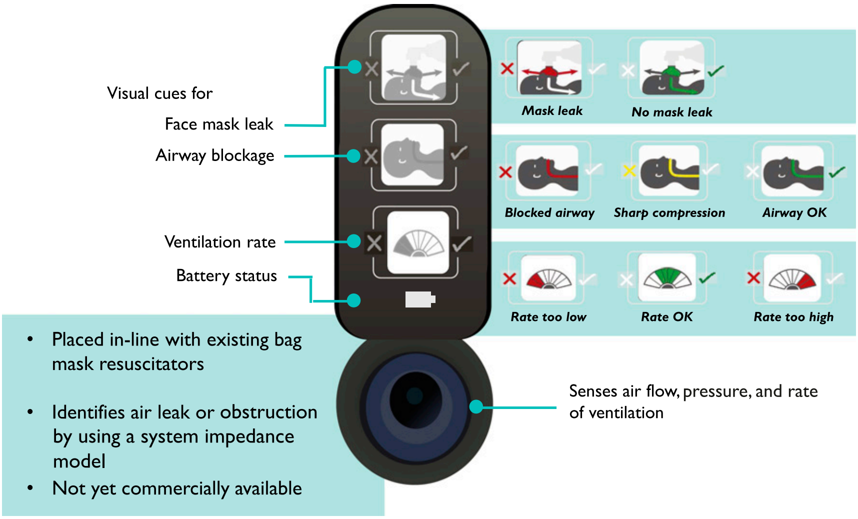

FIGURE 3
Technical illustration highlighting key features of the AIR.

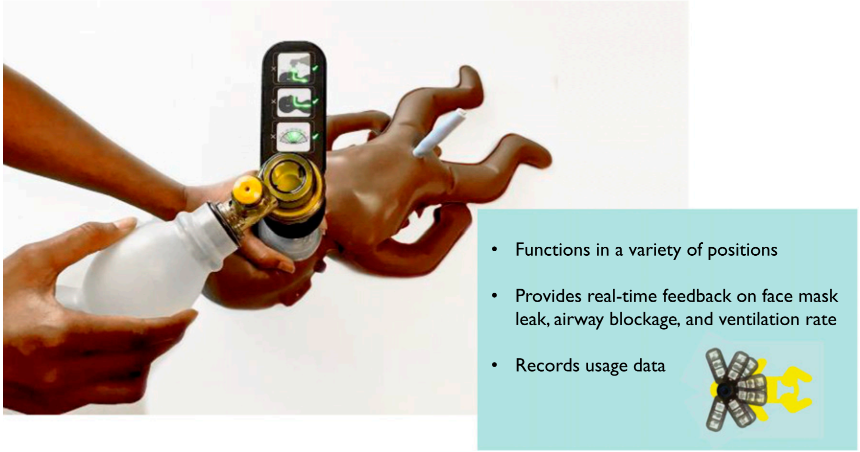

FIGURE 4
Features of the AIR for use during ventilation training.

longer, and build resuscitation confidence through its provision of real-time feedback on ventilation quality during simulated resuscitations. Further technical development will expand its application into a clinical tool for use during bedside resuscitations of newborns as well as children and adults.

Implementation in the Field

The AIR has been evaluated in one multicenter randomized controlled trial of simulated resuscitations. In the trial, researchers evaluated the impact of the AIR on effective ventilation of the NeoNatalie manikin with 270 providers in Uganda and the United States. Providers using the AIR achieved effective ventilation 14 seconds sooner than the control group ($P < .0001$) with a duration of effective ventilation that was 24 seconds longer ($P < .0001$).[23,24]

In a cost-effectiveness study, the AIR was calculated to cost US $24.44 per disability-adjusted life-year averted, putting it only slightly higher than the cost of HBB implementation, which is estimated at US $13 to $24 per disability-adjusted life-year averted.[21] The authors assumed a 30% reduction in the interval from initiation of BMV to recognition and correction of face mask leak on the basis of performance of the AIR in simulated resuscitations. Of note, the actual impact of the AIR on time to recognition and correction of face mask leak at the bedside is still to be determined.

The AIR may be a useful companion for HBB courses and LDHF training as an objective method of assessing the efficacy of BMV. Providers using the AIR device can learn their ventilation strengths and weaknesses without the assistance of a ventilation expert and/or mentor and then take corrective action or elicit targeted skills support from a peer. Additionally, the AIR device could be an objective tool for the evaluation of HBB. For example, a comparative study testing the efficacy of a mobile application to train providers in HBB is evaluating effective ventilation as an outcome using the AIR.[25]

Areas for Further Research

The AIR has been primarily validated for use in simulation training. However, when the training-only device was trialed by using computerized lung models simulating infants of varying sizes and lung mechanics, it demonstrated a 73.5% accuracy, signifying promise for future clinical-use development.[22,26] In future studies, researchers should also evaluate (1) the feasibility and acceptability of its use in LMICs and HICs, (2) the correlation between AIR device use in LDHF practice on bedside resuscitation outcomes, and (3) the role of ventilation practice data from the AIR device for evaluating resuscitation programs as well as implementation planning.

NEOBEAT: BATTERY-OPERATED HEART RATE MONITORING

Background

An assessment of heart rate immediately at birth aids a provider in determining the effectiveness of a newborn's breathing as well as the newborn's need for subsequent intervention. Furthermore, an increase in heart rate is the most sensitive indication of a newborn's positive response to an intervention such as BMV (as compared to an assessment of chest rise, breathing, color, or tone).[27] ILCOR recommends the measurement of heart rate during newborn resuscitation, stating that ECG can be used for rapid and accurate estimation of heart rate for newborns requiring resuscitation (weak recommendation, very low-quality evidence).[28]

Frequent or continuous monitoring of heart rate has been impractical to date in LMICs. In low-resource settings, heart rate is typically assessed via palpation of the umbilical cord or auscultation of the chest with a stethoscope. These methods are less accurate than ECG.[27] Furthermore, given the frequent reality of a single provider attending deliveries in LMICs, assessment of heart rate requires pausing or delaying other life-saving interventions such as BMV. To date, ECG technology used in HICs has been both cost prohibitive and impractical in LMICs given the cumbersome application of multiple electrodes by a single provider. As such, ILCOR has also called for improved technology for rapid application of ECG.[28]

Recognizing these limitations, the HBB algorithm primarily relies on assessment of the newborn's respiratory status to guide resuscitation interventions. HBB calls for an assessment of heart rate only after one minute of BMV with good chest movement (or sooner if there is a helper who can assess heart rate). A low-cost ECG device that can be rapidly applied to measure newborn heart rate in LMICs could alter this paradigm.

Device Description

NeoBeat is a low-cost heart rate meter designed by Laerdal Global Health for the measurement of newborn heart rate.[29] NeoBeat incorporates dry-electrode ECG into a snug-fit U-shaped device with a QRS detection algorithm that analyzes the signal (Fig 5). The device comes in 2 sizes: NeoBeat for newborns 1.5 to 5 kg (3.3 to 11 lb), and NeoBeat Mini for newborns 0.8 to 2 kg (1.7 to 4.4 lb).

NeoBeat can be placed rapidly on the upper abdomen of a newborn by a single provider and, within 5 seconds of placement, it digitally displays the heart rate (Fig 6). The device is also enabled with Bluetooth Low Energy for wireless live streaming of data, captured data transfer, firmware upgrade, and configuration. NeoBeat can be reused after cleaning and is rechargeable.

Implementation in the Field

Misclassification of early neonatal deaths as stillbirths is a common occurrence in LMICs.[12] A predecessor of NeoBeat was used in a cross-

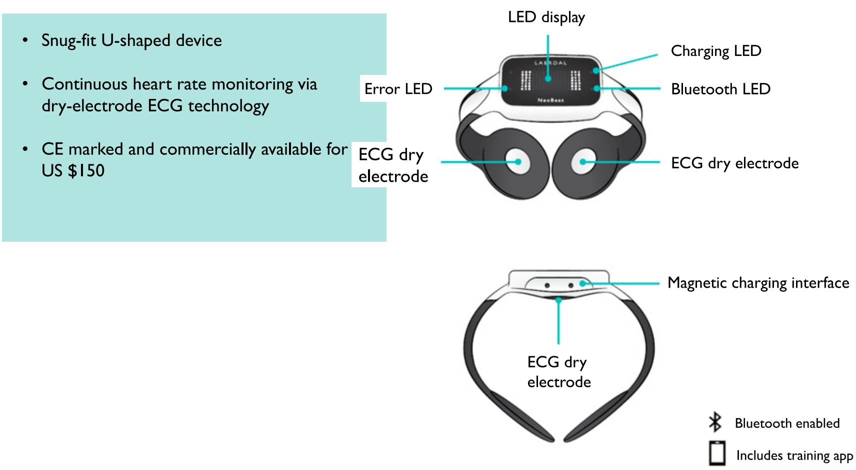

FIGURE 5
Technical illustration highlighting key features of NeoBeat. CE, certified in the European Economic Area to meet health, safety and environmental protection standards; LED, light-emitting diode.

sectional study in rural Tanzania to explore the clinical difficulty of distinguishing fresh stillborn from severely asphyxiated newborns. In this study, the authors characterized heart rate among nonbreathing flaccid neonates in relation to their classification as a stillbirth or early neonatal death.[30] NeoBeat detected a heart rate in 58% of 46 fresh stillbirths compared to 95% of 55 early neonatal deaths ($P < .001$). The initial heart rate was significantly lower in the stillbirth group (52 ± 19 vs 76 ± 37 in early neonatal deaths; $P = .003$). Heart rate at discontinuation of ventilation was detected among a greater proportion of early neonatal deaths than fresh stillbirths (95% vs 59%; $P < .001$). In a pre-post clinical newborn resuscitation trial in the Democratic Republic of the Congo (DRC), researchers are evaluating the effectiveness of HBB with NeoBeat for the detection of vital status on reported stillbirths compared to usual care (www.clinicaltrials.gov [identifier NCT03799861]).[31] This trial completed enrollment of ~25 000 newborns in 3 maternity units in Kinshasa, where midwives are the primary providers of newborn resuscitation. Results from this trial are forthcoming. Finally, live data capture of NeoBeat demonstrates that it has been used on a total of ~17 000 newborns since May 2019 and in multiple countries (Tanzania, the DRC, Nepal, and Norway).

The effect of NeoBeat on respiratory depression and newborn mortality is under study through the above trial in the DRC as well as a study in Nepal. The trial in the DRC will also evaluate the impact of a heart rate–guided algorithm using NeoBeat on effective breathing at 3 minutes after birth compared to HBB. The heart rate–guided algorithm adapts HBB to include earlier ventilation of newborns with a heart rate <100 beats per minute (immediately after drying), as well as improvement of ventilation based on heart rate. This trial is also being used to investigate the feasibility and acceptability of NeoBeat. Additionally, an implementation study in Nepal is incorporating NeoBeat into a larger quality improvement package centered on delivery room care.[15] Details of this trial were previously discussed in the section of this article on NeoNatalie Live; results are also forthcoming.

Given the ease of placement compared to traditional ECG leads, NeoBeat may also have application in HICs. In a multicenter interventional clinical trial in Norway, researchers are enrolling newborns to evaluate the efficacy of NeoBeat on ventilation performance and short-term outcomes compared to standard of care (www.clinicaltrials.gov [identifier NCT03849781]).[32]

Areas for Further Research

NeoBeat may enhance providers' ability to distinguish between live birth and stillbirth. This could improve classification and counting of these deaths and thus have tremendous public health relevance. However, the impact of improved classification of stillbirths on clinical care remains uncertain. Fresh stillbirths and severely asphyxiated newborns are part of the same clinical pathway, and distinguishing between the two is not critical for the implementation of interventions that reduce these outcomes. HBB recommends resuscitation of the flaccid newborn, with later determination of stillbirth if there is

FIGURE 6
Features of NeoBeat for use during bedside resuscitations.

no response to the resuscitation efforts. This approach circumvents the need to determine if a neonate is stillborn at the time of delivery, as does the use of perinatal mortality as a metric for resuscitation interventions. In future research, authors should consider the psychological and motivational impact of NeoBeat on providers' clinical response to severely asphyxiated newborns.

NeoBeat may also help providers with decision support to initiate BMV more quickly and to monitor the efficacy of BMV. The study of NeoBeat in the DRC will evaluate the impact of heart rate–guided HBB with NeoBeat compared to standard HBB. If there is evidence of improvement, a larger trial designed to evaluate its impact on perinatal mortality as well as cost-effectiveness will be warranted before large-scale implementation of NeoBeat can be recommended.

Thus far, the focus on NeoBeat has been with regard to delivery room care. In future studies, researchers should also explore its utility in care beyond the delivery room. For example, this tool may be useful in LMICs for ongoing monitoring or during transport of critical patients.

CHALLENGES AND OPPORTUNITIES RELATED TO IMPLEMENTING NEW DEVICES

Technology has significantly strengthened training and bedside resuscitation in HICs. Emerging technology could hold the promise of similar gains in LMICs. However, although the incorporation of technology into clinical care may be appealing, caution is warranted before technologies are adopted and scaled. In the sections that follow, we highlight challenges and opportunities related to introducing new devices on the basis of our collective experience in the field.

Implementing New Devices During Training

Implementation of HBB has revealed the challenge of translating training into improved care. Although the introduction of new training devices such as high-fidelity simulators and feedback devices has the potential to improve knowledge and skills acquisition, the challenge remains to implement such training in a manner that maximizes its translation. A significant portion of implementation funding should be allocated toward the translation of training into practice.

We suggest a hierarchy of building blocks to translate training into improved care (Fig 7). Beyond the essential first step of making training tools available, accountability for training coupled with evaluation of training progress is essential. Progress with training should be accompanied by regular self-reflection to link training to clinical practice. Self-reflection should, in turn, inform training so that training clearly addresses gaps found in clinical practice. This will increase the value of training to providers and improve motivation for these activities in an overburdened health care system. Regular progress and reflection will result in improved translation at the bedside.

The success of these steps may rely on the designation of an in-facility provider to champion these activities. For example, implementation in Tanzania has revealed that regular use of NeoNatalie Live increases when hospital management or designated providers within the labor ward champion its use. Similarly, NeoNatalie Live has been successfully adopted in facilities in Nepal because of peer practice coordinators charged with training providers and securing the manikin when not in use.

Attention to all of these building blocks is paramount to ensure a sustainable system in which training is not only feasible but also motivating, relevant, and effective. Technology-driven training outside of a framework for translation is unlikely to have sustained benefit.

Implementing New Devices During Bedside Resuscitation

Although the lure of new technology in the clinical environment may result in enthusiasm from providers, several challenges must be surmounted to effectively scale new devices. These include training of providers, adaptations to existing workflow, and integration into the ecosystem (Fig 8).

New technology should be paired with training to promote effective adoption. The time and resources required for training are dependent on properties of the device itself such as its novelty or complexity. In our experience, training some providers directly and expecting them to disseminate training may not be adequate for adoption. Additionally, on-the-job training may need to accompany one-

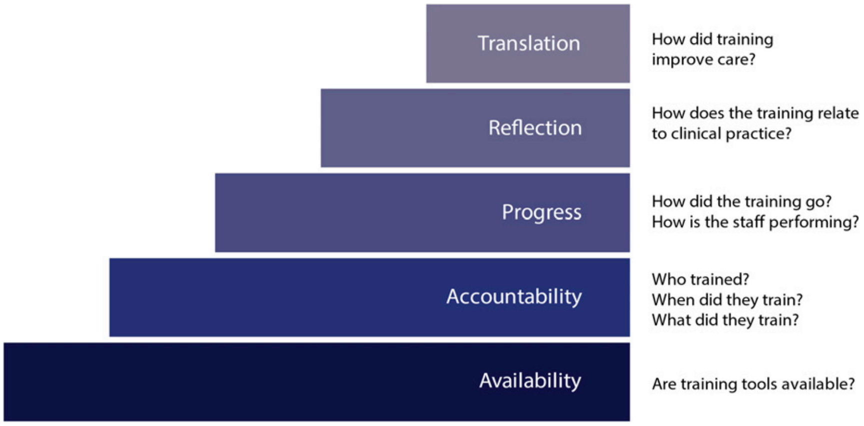

FIGURE 7
Building blocks to translate training to improved care.

time training sessions to ensure proficiency. Insufficient training can lead to hesitation in using the device, misuse of the device, and even unfounded doubt or overconfidence in the capabilities of the device.[33] For example, although ECG using a device such as NeoBeat is a reliable method of detecting heart rate, the technology has its limitations. When rhythmic changes in electrical activity are difficult to detect, often due to low or no heart rate, NeoBeat may display sporadic numbers that reflect detection of artifacts. Well-trained providers know that sporadic readings of heart rate are not reliable, and clinical confirmation is required.

Fully incorporating new devices into clinical care often requires adaptations to existing workflow to successfully accommodate its use. These adaptations should be fully considered before introduction of the device into clinical care, and may include aspects such as which staff will use the device, for which patients, and in what circumstances. Buy-in from providers for workflow adaptations may be challenging to obtain in the setting of high patient-to-provider ratios and resultant heavy workloads that reduce capacity and motivation to disrupt existing workflow. Providers may quickly see the value of devices that remove extraneous tasks or reduce stress on the system. Furthermore, acceptability of the device to end beneficiaries can be an important component of ensuring adoption.

Introduction of a new device into the clinical environment also requires attention to the ecosystem in which it is introduced. For example, an electrical source for charging may be required, as well as supplies for cleaning and disinfection. A plan should be made for how best to secure the device while maintaining its accessibility. Consideration for reprocessing should include when, how often, and who will complete the task. New technology requires maintenance as well as servicing; a clear method for obtaining technical support should be outlined so that the device is not abandoned when it malfunctions. Finally, many new devices now come with the promise of data for review; considerations for security of the data and space for data storage are also important.

Given the complex challenges involved in effective scale-up, new devices should provide clear value and have high potential for improving care. They should be durable and easy to use, as well as developed with input from end users and consideration for the health care system that will adopt them. Hospital management should be integrally involved in decisions to adopt new technology so that systems changes required for implementation are adequately supported. Device adoption that is supported by local ministries of health may be more likely to be sustained.

CONCLUSIONS

Cardiorespiratory monitoring during training as well as bedside resuscitations may improve resuscitation care and newborn outcomes in LMICs. Designing devices to meet the challenges of LMICs requires considerable innovation. NeoNatalie Live, the AIR, and NeoBeat represent a few of the innovations developed in recent years to support resuscitation care with HBB. Although cardiorespiratory monitoring devices hold promise, more data are needed to understand their impact on newborn outcomes in LMICs. Early adopters of these devices should share their experiences broadly so that we can better understand the salient issues around their implementation.

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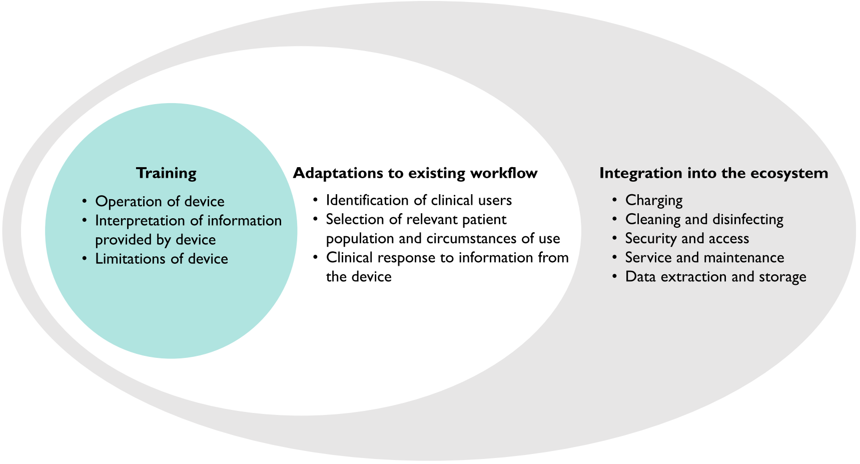

FIGURE 8
Considerations for training, adaptations to existing workflow, and integration into the ecosystem when implementing new devices.

ABBREVIATIONS

AIR: Augmented Infant Resuscitator
BMV: bag mask ventilation
DRC: Democratic Republic of the Congo
ECG: electrocardiogram
HBB: Helping Babies Breathe
HIC: high-income country
ILCOR: International Liaison Committee on Resuscitation
LDHF: low-dose high-frequency
LMIC: low- and lower-middle–income country

FINANCIAL DISCLOSURE: Ms Girnary and Dr Eilevstjønn are both employees of Laerdal Medical, the developer of NeoNatalie Live and NeoBeat. Dr Data is one of the developers of the Augmented Infant Resuscitator; the other authors have indicated they have no financial relationships relevant to this article to disclose.

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REFERENCES

1. Lawn JE, Blencowe H, Oza S, et al; Lancet Every Newborn Study Group. Every Newborn: progress, priorities, and potential beyond survival. [published correction appears in *Lancet*. 2014;384(9938):132]. *Lancet*. 2014;384(9938):189–205
2. Sankar MJ, Natarajan CK, Das RR, Agarwal R, Chandrasekaran A, Paul VK. When do newborns die? A systematic review of timing of overall and cause-specific neonatal deaths in developing countries. *J Perinatol*. 2016;36(suppl 1): S1–S11
3. Lawn J, Shibuya K, Stein C. No cry at birth: global estimates of intrapartum stillbirths and intrapartum-related neonatal deaths. *Bull World Health Organ*. 2005;83(6):409–417
4. Goudar SS, Somannavar MS, Clark R, et al. Stillbirth and newborn mortality in India after Helping Babies Breathe training. *Pediatrics*. 2013;131(2). Available at: www.pediatrics.org/cgi/content/full/131/2/e344
5. Msemo G, Massawe A, Mmbando D, et al. Newborn mortality and fresh stillbirth rates in Tanzania after Helping Babies Breathe training. *Pediatrics*. 2013;131(2). Available at: www.pediatrics.org/cgi/content/full/131/2/e353
6. Mduma E, Ersdal H, Svensen E, Kidanto H, Auestad B, Perlman J. Frequent brief on-site simulation training and reduction in 24-h neonatal mortality—an educational intervention study. *Resuscitation*. 2015;93:1–7
7. Kc A, Wrammert J, Clark RB, et al. Reducing perinatal mortality in Nepal using Helping Babies Breathe. *Pediatrics*. 2016;137(6):e20150117
8. Dol J, Campbell-Yeo M, Murphy GT, Aston M, McMillan D, Richardson B. The impact of the Helping Babies Survive program on neonatal outcomes and health provider skills: a systematic review. *JBI Database Syst Rev Implement Reports*. 2018;16(3):701–737
9. Evans CL, Bazant E, Atukunda I, et al. Peer-assisted learning after onsite, low-dose, high-frequency training and practice on simulators to prevent and treat postpartum hemorrhage and neonatal asphyxia: a pragmatic trial in 12 districts in Uganda. *PLoS One*. 2018; 13(12):e0207909
10. Huang J, Tang Y, Tang J, et al. Educational efficacy of high-fidelity simulation in neonatal resuscitation training: a systematic review and meta-analysis. *BMC Med Educ*. 2019; 19(1):323
11. Ersdal HL, Vossius C, Bayo E, et al. A one-day "Helping Babies Breathe" course improves simulated performance but not clinical management of neonates. *Resuscitation*. 2013;84(10):1422–1427
12. Gurung R, Litorp H, Berkelhamer S, et al. The burden of misclassification of antepartum stillbirth in Nepal. *BMJ Glob Health*. 2019;4(6):e001936
13. Safer Births. NeoNatalie Live. Available at: www.saferbirths.com/portfolio_page/newborn-ventilation-trainer/. Accessed April 26, 2020
14. Gurung R, Gurung A, Sunny AK, et al. Effect of skill drills on neonatal ventilation performance in a simulated setting- observation study in Nepal. *BMC Pediatr*. 2019;19(1):387
15. Gurung R, Jha AK, Pyakurel S, et al. Scaling Up Safer Birth Bundle Through Quality Improvement in Nepal (SUSTAIN)-a stepped wedge cluster randomized controlled trial in public hospitals. *Implement Sci*. 2019;14(1):65
16. Bhanji F, Donoghue AJ, Wolff MS, et al. Part 14: education: 2015 American Heart Association guidelines update for cardiopulmonary resuscitation and emergency cardiovascular care. *Circulation*. 2015;132(18 suppl 2): S561–S573
17. Mancini ME, Soar J, Bhanji F, et al; Education, Implementation, and Teams Chapter Collaborators. Part 12: education, implementation, and teams: 2010 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science With Treatment Recommendations. *Circulation*. 2010; 122(16 suppl 2):S539–S581
18. Bang A, Patel A, Bellad R, et al. Helping Babies Breathe (HBB) training: what happens to knowledge and skills over time? *BMC Pregnancy Childbirth*. 2016; 16(1):364
19. Wood FE, Morley CJ, Dawson JA, et al. Improved techniques reduce face mask leak during simulated neonatal resuscitation: study 2. *Arch Dis Child Fetal Neonatal Ed*. 2008;93(3):F230–F234
20. van Vonderen JJ, Witlox RS, Kraaij S, te Pas AB. Two-minute training for improving neonatal bag and mask ventilation. *PLoS One*. 2014;9(10):e109049
21. Ali A, Nudel J, Heberle CR, Santorino D, Olson KR, Hur C. Cost effectiveness of a novel device for improving resuscitation of apneic newborns. *BMC Pediatr*. 2020;20(1):46
22. Bennett DJ, Itagaki T, Chenelle CT, Bittner EA, Kacmarek RM. Evaluation of the Augmented Infant Resuscitator: a monitoring device for neonatal bag-valve-mask resuscitation. *Anesth Analg*. 2018;126(3):947–955
23. Data S, Cedrone K, Wright J, Olson K. Objective feedback improves resuscitation training and practice. Available at: https://www.who.int/medical_devices/global_forum/3rd_gfmd/resuscitationtrainingpractice.pdf?ua=1. Accessed April 26, 2020
24. GBC Health. Innovations in global health: Augmented Infant Resuscitator empowers birth attendants to save newborns. Available at: www.gbchealth.org/innovations-in-global-health-air/. Accessed April 21, 2020

25. Merali HS, Chan NH, Mistry N, et al. Designing and evaluating a novel mobile application for Helping Babies Breathe skills retention in Uganda: comparative study protocol. *BMJ Paediatr Open*. 2019;3(1): e000561

26. IngMar Medical. ASL 5000 breathing simulator. Available at: https://www.ingmarmed.com/product/asl-5000-breathing-simulator/. Accessed May 13, 2020

27. Phillipos E, Solevåg AL, Pichler G, et al. Heart rate assessment immediately after birth. *Neonatology*. 2016;109(2): 130–138

28. Perlman JM, Wyllie J, Kattwinkel J, et al; Neonatal Resuscitation Chapter Collaborators. Part 7: neonatal resuscitation: 2015 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science With Treatment Recommendations. *Circulation*. 2015;132(16 suppl 1): S204–S241

29. Laerdal Medical. NeoBeat newborn heart rate meter. Available at: https://laerdalglobalhealth.com/products/neobeat-newborn-heart-rate-meter/. Accessed April 26, 2020

30. Ersdal HL, Eilevstjønn J, Linde JE, et al. Fresh stillborn and severely asphyxiated neonates share a common hypoxic-ischemic pathway. *Int J Gynaecol Obstet*. 2018;141(2): 171–180

31. ClinicalTrials.gov. Newborn heart rate as a catalyst for improved survival. Available at: https://clinicaltrials.gov/ct2/show/NCT03799861. Accessed October 28, 2019

32. National Library of Medicine. The NeoBeat efficacy study for newborns. 2019. Available at: https://clinicaltrials.gov/ct2/show/NCT03849781. Accessed April 26, 2020

33. Rivenes Lafontan S, Sundby J, Kidanto HL, Mbekenga CK, Ersdal HL. Acquiring knowledge about the use of a newly developed electronic fetal heart rate monitor: a qualitative study among birth attendants in Tanzania. *Int J Environ Res Public Health*. 2018; 15(12):E2863

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Jackie K. Patterson, Sakina Girnary, Krysten North, Santorino Data, Daniel Ishoso, Joar Eilevstjønn and Carl L. Bose

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