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Future medical education in pediatrics and neonatology

Edited by
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Future medical education in pediatrics and neonatology

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Editorial: Future medical education in pediatrics and neonatology

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Editorial on the Research Topic
Future medical education in pediatrics and neonatology

Pediatric and neonatal emergencies generate high-stress levels and an immense cognitive load for healthcare providers. For decades, a “see one, do one, teach one” approach was a common strategy within medical training (1). However, this approach is a challenge for patient safety, as providers used to perform procedures on patients for the very first time. Nowadays, a “see one, simulate many, do many, teach one” is acknowledged as more appropriate, where students and healthcare providers can practice skills and emergencies safely without harming patients (2). Simulation-based medical education is usually performed as either low-fidelity or high-fidelity training utilizing manikins and specific technology for on-site training (3). However, the COVID-19 pandemic demonstrated that traditional simulation-based medical education is not preserved from the outage and that healthcare and educational systems should be prepared for new educational challenges such as virtual teaching approaches (4). In this special issue of Frontiers in Pediatrics about future medical education in pediatrics and neonatology, we aimed to collect research articles focusing on promising and innovative new teaching methods for student training and clinical education.

Virtual teaching

One strategy to overcome traditional training approaches with the need to be on-site, often limited due to staff shortages and lack of space to perform training, is a switch to virtual education strategies. Recently, there has been a significant increase in serious game applications (5). Serious games can augment learning and establish continuous algorithm and decision-making skills (5). The authors Bardelli et al. introduced a new computer game called “DIANA: Digital Application in Newborn Assessment”, which enables virtual training of neonatal life support on a computer, and the authors demonstrated the equivalence of this virtual training to conventional training. Furthermore, telemedicine for tele-simulation was also described as an option for distance training with the advantage of integrating external experts from other countries in the skill or team training process (6, 7). Löllgen et al. combined both serious gaming and tele-simulation utilizing avatars as surrogates for human participants to enable remote team training in multiple institutions simultaneously. They suggested this methodology as a feasible alternative to connect educators and trainees virtually at the same place. Whereas this training needs to be synchronized for participants, Wellmann et al. presented an asynchronous online training course with evidence-based content for neonatologists internationally.

However, future challenges will include the optimal integration and utilization of serious games and research on the outcome of virtual teaching methods on students' and healthcare providers' knowledge and preservation of psychological safety in a remote virtual setting.

Individualized training

Future training approaches often utilize new technology or media (feedback devices, ultrasound, eye-tracking, augmented reality, video recording, 3D printing) compared to traditional training strategies or methods. These technologies are used and discussed for training and integration in clinical settings for real-time assessment (8). The utilization of video recording is an excellent example of how technology can be used to record simulations or real clinical situations for clinical education and research. After a critical or even only after a routine situation, a video recording, either with a designated video recording system or from a first-person perspective using eye-tracking glasses (9), can be reflected together with the whole team to identify problems such as the environment, the algorithm adherence, or teamwork and communication. After that, this knowledge can be used for targeted training to improve the workflow in the delivery room, intensive care unit, and individual and team behavior. Heesters et al. described in their article the integration of video recording and reflections in their local setting in combination with a narrative review about this technology for a change in team culture and an increase in patient safety. The article gives an excellent overview of necessary preconditions, technical issues, and the organization of video debriefings. While the optimal video recording system still needs to be determined, there are some advantages when using eye-tracking glasses, such as a first-person perspective as well as insights into the visual behavior of healthcare providers. This new technology has the potential to identify human factor issues and to learn more about individual behavior during routine and critical situations. Anesthetists have previously used this technology and identified visual attention's influence on individual performance and workload (10). Gröpel et al. used eye-tracking in a cross-over randomized simulation trial and identified that a specific gaze behavior with a strong focus on the patient and a minimum of gaze transitions was correlated with improved outcomes of ventilations and chest compressions. Furthermore, this technology can be used for telemedicine, tele-simulation approaches, and generating new data in simulation-based medical education.

Besides video recording as a new educational tool, integrating objective feedback devices can play a significant role in training and supervision. Nowadays, most of the training is still performed using an instructor's subjective feedback. However, it has been shown that adding an objective feedback device, such as a respiratory function monitor, leads to better trainees' performance (11). Rod et al. confirmed that using a respiratory function monitor as objective feedback improved ventilation parameters. Moreover, real-time feedback in simulated and clinical situations can potentially decrease workload and improve patient outcomes. However, there are still many research questions about the optimal integration within a specific environment and the human-technology interaction before they can be recommended for routine use. Nevertheless, continuous data acquisition with feedback devices can help collect knowledge on individual performance.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication. All authors contributed to the article and approved the submitted version,

Conflict of interest

MW is part of the medical advisory board of Soma Reality GmbH and received grants from the Austrian Research Promotion Agency, Medical-Science Fund of the Mayor of Vienna, ESPNIC Medtronic Research Grant, Society for Neonatology and Pediatric Intensive Care for conducting research using video recording, eye-tracking, respiratory function monitoring, and virtual reality. PD has no conflict of interest to declare. GMS is the owner of RETAIN Labs Medical Inc, which produces and distributes serious games for neonatal resuscitation training. GMS has received funding as either Principal Investigator or as Co-Investigator to study various aspects of the neonatal resuscitation algorithm. These funding agencies include the Canadian Institute for Health Research, National Institutes of Health - USA, National Health and Medical Research Council - Australia, THRASHER Foundation, Laerdal Foundation.

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MINI REVIEW
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Umbilical Venous Catheter Update: A Narrative Review Including Ultrasound and Training

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The umbilical venous catheter (UVC) is one of the most commonly used central lines in neonates. It can be easily inserted soon after birth providing stable intravenous access in infants requiring advanced resuscitation in the delivery room or needing medications, fluids, and parenteral nutrition during the 1st days of life. Resident training is crucial for UVC placement. The use of simulators allows trainees to gain practical experience and confidence in performing the procedure without risks for patients. UVCs are easy to insert, however when the procedure is performed without the use of ultrasound, there is a quite high risk, up to 40%, of non-central position. Ultrasound-guided UVC tip location is a simple and learnable technique and therefore should be widespread among all physicians. The feasibility of targeted training on the use of point-of-care ultrasound (POCUS) for UVC placement in the neonatal intensive care unit (NICU) among neonatal medical staff has been demonstrated. Conversely, UVC-related complications are very common and can sometimes be life-threatening. Despite UVCs being used by neonatologists for over 60 years, there are still no standard guidelines for assessment or monitoring of tip location, securement, management, or dwell time. This review article is an overview of the current knowledge and evidence available in the literature about UVCs. Our aim is to provide precise and updated recommendations on the use of this central line.

Keywords: umbilical venous catheters, POCUS, CRBSI (catheter-related bloodstream infection), catheters and catheterization complications, catheters and catheterization, technology, training

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INTRODUCTION

The umbilical venous catheter (UVC) is one of the most frequently used central venous access devices in the neonatal period. It can be easily placed and it is extremely useful for preterm and/or for critically ill infants requiring frequent blood sampling and intravenous administration of fluids, medications, and parenteral nutrition. The correct tip location is at the junction between the inferior vena cava (IVC) and the right atrium (RA), which can be reached after entering the umbilical vein and passing through the ductus venosus (DV) (1–5). This position is considered to be associated with the lowest incidence of complications.

For decades, thoracoabdominal radiograph (TAR) has been used to assess the position of the catheter's tip, but over the past few years ultrasonography has been suggested as the gold standard technique since it is safe, fast, and more accurate. Ultrasound is also ideal for daily evaluation of tip location, since tip migration may occur frequently (6–13). Indeed, UVC-related complications can be very severe, so it is important to check the catheter's tip over time and to keep in mind the possible implications of this central line.

Although neonatologists have been using UVCs for more than 60 years, the standard of care in the management of such a device is still a matter of debate. For instance, the most appropriate indwelling time and the best method for securement are still not well-defined.

The goal of this narrative review is to offer a practice-oriented overview on UVCs, looking at the more advanced technologies, some of which is already evidence-based, that might improve clinical outcomes.

INDICATIONS AND INDWELLING TIME

UVC is frequently used in the neonatal intensive care unit (NICU) because it provides safe vascular access immediately after birth in high-risk newborns. UVCs are typically used for intravenous administration of parenteral nutrition and drugs, for blood sampling, and for blood transfusions (14).

At the time of insertion, it is often not easy to predict the clinical course of the newborn, so there is a significant risk of overusing this device, especially in preterm infants.

In a quality improvement document aiming at reducing unnecessary placement of UVCs, Shahid et al. (15) developed a consensus guideline providing indications for UVC placement on the basis of gestational age (GA), severity of illness, and difficulty of establishing peripheral intravenous vascular (PIV) access. They recommended the use of UVC in all preterm infants ≤28 weeks, and in newborns ≥29 weeks mechanically ventilated or with FiO_2 >40% on continuous positive airway pressure and/or hemodynamically unstable and/or needing inotropes or fluids bolus, or with difficulty establishing PIV access.

According to the Michigan Appropriateness Guide for Intravenous Catheters in pediatrics recommendations (16), the use of UVC in term neonates is influenced by the infusate characteristics, expected duration of therapy, and age of the neonate. In this document, the insertion of UVC is considered appropriate up to day 5 after birth for non-peripherally compatible infusions. The Centers for Disease Control and Prevention Hospital Infection Control Practices Advisory Committee recommends that UVCs should be removed as soon as possible, but they can be used for up to 14 days if absolutely needed and if managed aseptically (17).

In 2012, Butler-O'Hara et al. (18) compared retrospectively UVCs with dwell time ≤7 vs. >7 days. The paper proved that the rate of central line-associated bloodstream infection (CLABSI) was 1/1,000 catheter days in the ≤7 days UVC group vs. 4/1,000 catheter days in the >7 days UVC group ($P < 0.001$). Other authors (19) suggested that UVCs should be removed earlier, before day 4, and replaced by another central venous catheter. In a multicenter retrospective study, the authors demonstrated that the risk of CLABSI is proportional to the dwell time of the UVC. In a systematic review, Keir et al. (20) concluded that if central access is required beyond 5–7 days, the UVC should be removed and replaced with another central line. INS 2021 guidelines suggest limiting UVC dwell time to 7–10 days and UVC removal at 4 days followed by insertion of a PICC for continued infusion as an infection prevention strategy (5).

CHOICE OF THE DEVICE

Polyurethane catheters are preferred over polyethylene and polyvinyl catheters, since they are less prone to bacterial colonization. Polyurethane UVCs that release antimicrobially active silver ions have recently become available in the market. These catheters are potentially associated with a reduced risk of CLABSI, since they decrease both endoluminal and extraluminal colonization (21). A single randomized controlled study (22) has demonstrated that these silver-impregnated UVCs are effective in decreasing the risk of catheter-related bloodstream infections (CRBSI) in preterm infants with gestational age < 30 weeks. Their use has also been recommended by SHEA guidelines in 2014 for prevention of CRBSI in preterm infants (23). However, looking at the data from the recent Cochrane study published in 2015 (24), it seems reasonable to recommend these catheters only for preterm infants and in the neonatal unit with a policy of long dwell time for UVC (more than 7 days). In fact, the Kaplan-Meier estimates clearly show that the differences in the risk of CRBSI between conventional UVCs and antimicrobial impregnated ones becomes clinically relevant for dwell time longer than 7 days.

As regards the caliber of the UVC, 3.5 Fr catheters are usually recommended for infants weighing <3.5 kg and 5 Fr catheters for infants weighing more than 3.5 kg. Double and triple-lumen catheters are available if simultaneous administration of incompatible solutions is anticipated. The use of multi-lumen catheters may reduce the need for additional PIVs and is recommended in low birth weight infants (25).

INSERTION OF THE UVC INCLUDING NEW TECHNOLOGIES

Several studies have tried to define the best length estimation technique during UVC insertion. In 1966, Dunn published a graph reference, mainly based on the distance between shoulder and umbilicus (26). Twenty years later, Shukla and Ferrara came up with a formula based on body weight (BW) (27), which was further modified by Verheij et al. (28). Another retrospective study proposed the use of distance from the umbilicus to the mid-xiphoid (29). One more formula has been proposed by Gupta (30). **Table 1** summarizes all these different methods. At present, there is no formula, nomogram, or measurement, that can be universally and effectively applied to infants of different BWs and Gas (13, 31, 32). Though, the methods most commonly used for estimation of catheter length are the Dunn formula and the Shukla formula. The Shukla formula has the highest rate of either correct or high position. The Dunn formula, on the other side, seems to perform quite poorly.

TABLE 1 | Different methods to estimate a correct UVC insertion length.

References	Study population	Results
Dunn (26)	50 UV (at necropsy) BW 680–4,027 g, EG 26–44 weeks	Shoulder-umbilicus distance
Shukla and Ferrara (27)	39 UV and 4 UA, BW 2,037 ± 1,077 g 10 UV, BW 2,260 ± 1,144 g	Lenght (cm) = [(3 * BW in Kg + 9) / 2 +1]
Verheij et al. (28)	143 UV using the Shukla formula 125 UV using the revised formula	Lenght (cm) = [(3 * BW in Kg + 9) / 2]
Vali et al. (29)	82 UV and 55 UA BW 1,311± 888 g, EG 23–27^{+6} weeks	Umbilicus-mid-xiphoid-bed distance
Gupta et al. (30)	170 UV, BW 490 ± 4,800 g, EG 24–41 weeks 125 UA, BW 490 ± 4,800 g, EG 24–41 weeks	Lenght (cm) = Umbilical-Nipple length – 1 cm

The Shukla formula had the highest rate of either correct or high position. The Dunn formula performed quite poorly.

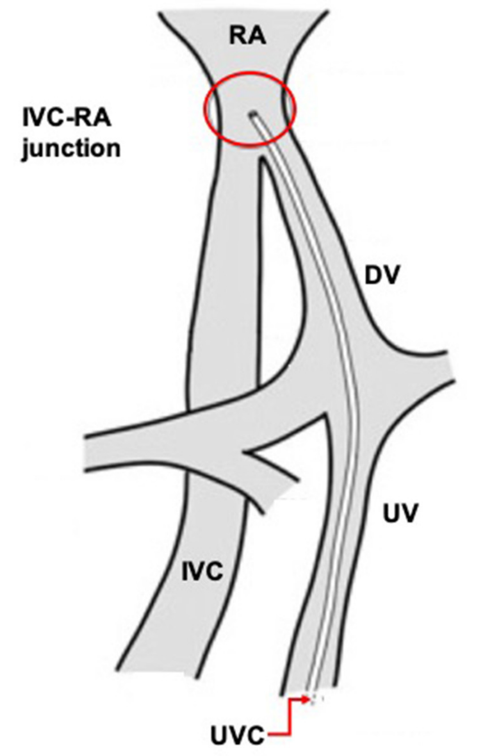

FIGURE 1 | Correct umbilical venous catheter position.

In emergency use, the UVC tip should be located only at a short distance, 2–4 cm, at the beginning of the umbilical vein to the point at which blood can be freely aspirated. Indeed, if the catheter is inserted further, there is risk of hepatic injury caused by infusing medications directly into the liver (33, 34).

At the time of insertion, the UVC first enters the umbilical vein, then the medial part of the left portal vein and the DV, eventually reaching the junction of IVC and RA (**Figure 1**). Unfortunately, the UVC might take some collateral route into the portal system and be accidentally located in an intrahepatic branch of the portal vein.

Observational studies showed that some maneuvers could facilitate UVC passage through the DV. Pennaforte et al. (35) have recommended the manual mobilization of the liver during UVC insertion. Other authors (36) have suggested placing the infant on the right side during UVC insertion, since this position might reduce the risk of tip progression into the portal venous circulation. Another maneuver suggested is the compression of the upper abdomen near the portal sinus of the liver, to align the umbilical vein and DV, under ultrasound guidance (37). The Accreditation Council for Graduate Medical Education (ACGME) expects pediatric residents to become competent in performing certain procedures during general pediatric practice, including umbilical line placement (38). Several authors have studied the most effective method for adequate training of pediatric residents in the placement of UVCs (39, 40). Haviland et al. conducted a study in which nine post-graduate 1st year residents completed a pre-training survey and simulation, and eight residents completed a post-training survey and simulation. The residents demonstrated an increase in objectively measured competence and self-rated confidence, despite lacking opportunities to perform the procedure on live neonates (41). Overall, simulation is an important component of residency training, especially since it allows residents to gain hands-on experience without risks to the patients.

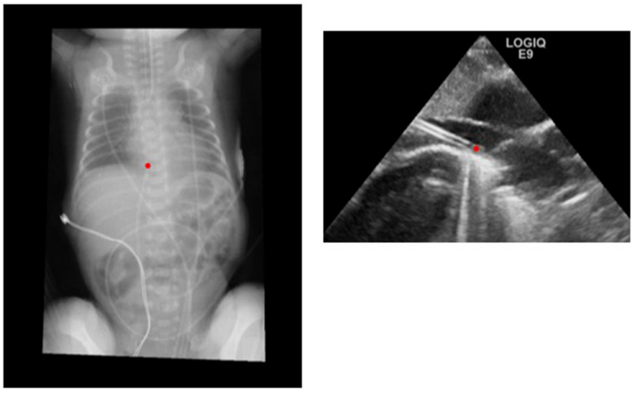

FIGURE 2 | Comparison of radiographic and ultrasound images of a correctly positioned UVC.

The newest and most interesting development in UVC insertion is indeed the introduction of ultrasound-based methods for tip navigation and tip location. The use of point-of-care ultrasound (POCUS) to visualize umbilical catheters during the procedure is rapidly spreading among neonatologists (11, 12, 42–44) (**Figure 2**).

In 2013, Pulickal et al. conducted a prospective observational study in which real-time ultrasonography was performed by a trained cohort of pediatric house staff physicians during UVC insertion (10). Many other studies confirmed the superiority and higher accuracy of intraprocedural ultrasound over post-procedural radiologic assessment (8, 45, 46). Chest X-ray is inaccurate as X-rays do not allow the visualization of the veins. Therefore, clinicians must infer the location of the tip of the catheters on the basis of other radiological landmarks such as the vertebral bodies, cardiac silhouette, and the diaphragmatic contour. On the other side, ultrasound allows a clear view of the vein and of the catheter itself. In the studies quoted, 20–25% of the catheters that were judged to be in a correct position on the chest X-ray were readjusted after the ultrasound was performed.

Despite all this evidence, POCUS is not universally used in NICU for this purpose, possibly because it needs specific and adequate training of the neonatal medical staff.

In a recent experimental study, Kaee et al. investigated the learning curve for targeted ultrasound evaluation of UVC placement in physicians with low experience in ultrasound use in a piglet model. After a short eLearning module and a few practical sessions, trainees were able to detect the catheter's tip with accuracy and high self-confidence score within 10 min (47). A recent pre/post intervention study demonstrated the feasibility of targeted training on the use of POCUS for UVC placement in NICU among neonatal medical staff. The technique was easily teachable, increased the number of UVCs correctly positioned, and reduced the number of line manipulations and chest X-rays (48).

Similarly, ultrasound performed by neonatal residents and neonatal nurse practitioners has good results in terms of diagnostic accuracy, after adequate training (49, 50).

Realtime ultrasound for tip navigation and tip location of UVC is accurate, safe, and cost-effective. It is reasonable to predict that real-time ultrasound will shortly become a new standard of care with the support of standardized protocols defining the proper technique (42).

SECUREMENT

Four different methods of UVC securement have been described (51). In the "anchoring" technique, the UVC is sandwiched between two small pieces of tape then reinforced by stitching from the tape through the umbilical cord or skin on both sides. In the technique of "bridging," two thin pieces of tape are placed on each side of the umbilicus in a T-shape and secured to the abdomen, another piece of tape is then bridged between the two T-pieces that holds the catheter in place. Another method uses a DuoDERM patch which is cut to fit the baby's chest and the umbilical catheter is rolled up and secured to it by a piece of transparent dressing. In the last technique, the UVC holder adheres to the skin with hydrocolloid gel and two flaps rise up from the base and open and close multiple times for adjustments. In many centers, the UVC is secured only using sutures, without tape or other adhesive materials, as described in McDonald's Atlas of Procedures in Neonatology (14). In conclusion, in the current literature there are no data that support one method over another, so the choice is made according to local guidelines, medical skills, and to the infant's conditions. A randomized controlled trial is in progress in our neonatal unit and proposes the use of cyanoacrylate glue applied to the umbilical stump to reinforce the securing suture and ensure a better stabilization (52). Probably a strategic choice could include the use of a sutureless device, the use of cyanoacrylate glue in order to provide immediate hemostasis and to prevent dislodgement, and the application of a transparent semipermeable dressing with a high level of moisture transmission rate.

CARE

A high standard level in the care of the UVC in NICU is crucial for the prevention of infective and mechanical complications. Particularly good clinical practice should include daily assessment and care of the exit site, proper securement, appropriate skin antisepsis, bundles for flush and lock, and administration set management.

UVC is a central line and therefore should be managed accordingly. We do recommend a thorough reading of the recent INS guidelines published in 2021 (5), that summarize the standard of care regarding administration set changes, the proper use of a needleless connector and port protector, and the appropriate policy of flushing and locking using normal saline with a prefilled syringe.

Currently there is no universal agreement on the appropriate skin antiseptic. However, the single use applicator containing 2% chlorhexidine in 70% isopropyl alcohol seems to be safe even in very low birth weight infants.

The main outstanding issue regarding the management of the UVC remains the proper securement and the care of the exit site. Unfortunately, no guideline is available yet about this topic and several approaches have been proposed in the literature.

POST-PROCEDURAL X-RAY

The most common method to confirm tip location is still the anteroposterior TAR. Two methods of radiograph interpretation have been described in literature. In the "cardiac silhouette" method, the position of the cavoatrial junction (the target zone) is estimated by extrapolating the curve of the right atrial border medially to its intersection with the IVC (which is best determined when the UVC passes through the IVC) or the right border of the vertebral bodies (if the UVC does not pass through the IVC). In the "vertebral body" method, the tip is defined as "well-positioned" when located at the level of T8–T9, "high" if above T8, and "low" if below T9 (53, 54). The "cardiac silhouette" method is more accurate than the "vertebral body" method (54).

Radiological methods of tip location should be discouraged. As compared to intraprocedural ultrasound (42), post-procedural radiological assessment of UVC position implies an inevitable delay in starting the infusions, is more invasive, more difficult from the logistic point of view, less accurate and less cost-effective, and—last but not least—it is less safe. In fact, in a retrospective analysis of 215 premature infants, Scott et al. (55) found that 12.1% of the infants with a GA <33 weeks received more than the maximum recommended ionizing radiation exposure (1,000 mSv) during their NICU stay and that central lines placement accounted for 19.2% of the total radiation exposure.

MIGRATION

Migration of UVC after insertion has been widely documented. Migration might occur in 50%, 63%, or even in 90% of cases (45, 56, 57). It is commonly attributed to the drying of Wharton jelly and the secondary shortening of the umbilical cord.

A prospective cohort study quantified the direction and the magnitude of catheter's tip migration (58). The authors described an inward migration pattern during the first 48 h after UVC placement, followed later by an outward migration. The inward migration was explained by cord stump contraction over time together with an increase in lung volume (due to the increase in the functional residual capacity, e.g., following surfactant administration), the outward migration instead was likely to result from gradual distension of the abdomen as the bowel filled with gas (58). About half the infants included in the studies experienced migration, mainly inward within 24–48 h from the catheter insertion (48, 59, 60).

The risk of tip migration is a strong reason for adopting ultrasound-based tip location, which can be safely repeated over time, even daily (42).

INFECTION

The use of any central line, including UVC, is always associated with the risk of infection. Prevention of CLABSI is fundamental as both neurodevelopmental and growth outcomes are negatively affected in infants with postnatally acquired infections (61). The most common microorganisms are coagulase-negative staphylococcus (CONS) followed by Gram-negative bacilli and fungi.

The use of UVCs has been associated with colonization in 22–59% of cases and with CRBSI in 3–20% of cases. This huge variability is mainly related to the mean dwell time throughout the different studies. CRBSI was defined by a culture of a peripheral, percutaneously obtained blood sample that was positive for the same organism found to be colonizing the UVC hub or tip (i.e., concordant colonization of the catheter hub or tip). Colonization means the presence of $\geq$15 CFU of a single organism per catheter if not accompanied by a laboratory-confirmed blood stream infection of the patient. In patients requiring long-term central venous access, CRBSI is reduced by nearly half after the institution of a dedicated vascular access team in NICU (62). Likewise, other authors showed that line bundles and dedicated line care teams decrease the risk of CRBSI and CLABSI (17, 63, 64).

NON-INFECTIVE COMPLICATIONS

UVCs are also potentially associated with severe non-infective complications (65).

UVC with the tip in the right atrium might be associated with cardiac complications. Fourteen cases of cardiac arrhythmias associated with UVCs have been reported in literature, mainly atrial flutter and paroxysmal supraventricular tachycardia (66). Cardiac tamponade caused by UVC is rare (0.5–2% incidence) but life-threatening, and it can occur even when the catheter is properly positioned. The pathogenesis is most likely due to erosion of the vascular or cardiac wall by the catheter leading to perforation. The hyperosmolar fluid infused through the line diffuses into the pericardial space (67, 68).

UVCs with the tip in the hepatic vessels or the portal system are associated with high risk of extravasation and consequent parenchymal injuries or portal thrombosis. Hepatic complications due to UVC malposition are common and widely described in numerous case reports (69, 70). Liver ultrasound is the gold standard to diagnose hepatic complications and to follow their evolution over time. Air in the portal venous system is the most frequent finding (20.1%), followed by parenchymal lesions (7.4%) and left portal venous thrombosis (6.1%) (69). The UVC tip can also cause a structural injury, including hepatic hematoma, due to a direct erosion or laceration of an intrahepatic vascular wall. Parenteral nutrition, inotropes, and hypertonic solutions can cause endothelial damage and leakage to the liver parenchyma, resulting in abscess, liver necrosis, or parenchymal tears (71–74). After disruption of the liver capsule and effusion of the collection into the peritoneum, ascites might be seen as a further complication of a malpositioned UVC (73, 75, 76).

Central venous umbilical catheterization is reported to be the most common cause of neonatal thrombosis (77). Catheter-related portal vein thrombosis (PVT) has been described as a rare event but is increasingly recognized thanks to the increased use of ultrasound evaluations when the UVC is in place and after its removal. Reported incidence varies from 2.2 to 43% due to differences in study design and methodology. UVC can cause thrombosis with different mechanisms: direct damage to vessel walls, disrupted blood flow, infusion of substances damaging endothelial cells, and introduction of a foreign thrombogenic surface (77, 78).

UVCs have also been associated with the development of intracardiac thrombosis, pulmonary embolism, and renal vein thrombosis due to tip malposition (79).

A recent prospective cohort study found a significant association between UVC malposition in the portal system or in the DV (low lying line) and an increased incidence of NEC in preterm infants (79, 80). In an experimental model, the authors demonstrated that transient portal hypertension might result from closure of the DV shortly after birth causing intestinal injury. This suggests the potential role of DV occlusion caused by UVC in the development of NEC in premature infants (81).

FUTURE MEDICAL EDUCATION OF UVC

UVC placement is a well-established procedure in NICU but nowadays we can take a glance into the future using some promising tools. Certainly, the use of the umbilical cord model opens up a new perspective for teaching catheter placement because it allows the physician, especially trainees, to gain proficiency and confidence with the procedure without risks for

TABLE 2 | Correct steps in UVC management.

1.	Choice of selected patients with precise indications
2.	Use of silver-impregnated catheters if plan to keep the device *in situ* for more than 7 days in preterm infants (recommended to prevent CRBSI)
3.	Line bundles and dedicated line care teams (recommended to prevent CRBSI)
4.	Use of point of care ultrasound to visualize catheter tip location during insertion and detect late catheter migration (to prevent mechanical complications)
5.	Early removal of UVC (within 4 days)

the patients. Sawyer et al. described how to create a real human umbilical cord simulator for emergency UVC placement training. The model used a fresh (rather than frozen) human umbilical cord, a newborn simulator with a hole in the abdomen for the umbilical cord, a baby bottle nipple and closure ring, a rubber exam glove, and an umbilical clamp or Kelly clamp (39). They then conducted a randomized crossover trial of senior pediatric residents randomized in groups each with a different UVC simulator, either a real cord (RC) or simulated cord (SC). The two groups then switched their simulators. The authors concluded that the time to place a UVC was slower in the residents using real cords as compared with the simulated cords, however, there was no difference in the time taken to place an eUVC in the group that worked with the simulated cords first (40). In our NICU the training program includes:

— theoretical instruction by an expert to first-year residents.
— practical exercises once a week on the simulator.
— after 3 months, evaluation of sequence procedure on simulator.
— the placement on the small patient is supervised by a senior resident at least 3 years old.
— after 20 UVC placements with supervision and the final evaluation, the resident is independent.

The use of POCUS for tip navigation and location during UVC placement is feasible in any setting, easy to teach, and easy to learn. It reduces catheter malpositioning and associated complications; it also allows safe administration of total parenteral nutrition reducing the waiting time that is usually necessary when X-rays are used. The subcostal longitudinal view is the most commonly used acoustic window, which allows staff to visualize the IVC and the RA, which are the targets. The tip is followed until it reaches the target zone. A small flush of normal saline (0.5–1 ml) can improve the visualization of the tip (42). Finally, the use of a wireless ultrasound probe connected with a smartphone or tablet could be very beneficial in the UVC's tip location. It is easy to use for any medical and paramedical operator, it can be used in emergencies, in training, and above all in the diagnostic management of the isolated patients (82).

Current technological advancements are providing new modalities for simulation-based training. One such promising approach is Augmented Reality (AR) which is created by combining real and virtual data with real-time interactivity and three-dimensional registration. A recent review of available AR applications revealed that although the use of this technology is gaining interest, data are still lacking to support its overall applicability and effectiveness (83). Categories of current AR applications were limited to the disciplines of laparoscopy, neurosurgery, and echocardiography. Currently there is no such paper in the field of venous access in newborns but AR could soon play a large role in neonatal vascular training.

CONCLUSION

UVC provides vascular access immediately after birth in preterm and/or critically ill infants who require fluid resuscitation, intravenous medications, and parenteral nutrition; it can be inserted painlessly and quickly. Nevertheless, an indwelling UVC is associated with many complications. The most effective way to minimize UVC-related adverse events is not to have an UVC in place. As a consequence, the need for UVC placement must be carefully evaluated by choosing selected patients with specific indications. Once in place, catheter management is crucial: line bundles and dedicated line care teams have been shown to decrease the risk of catheter-related infections and the use of POCUS has been proved to be an invaluable tool to prevent complications related to UVC malposition and migration.

Given the high risk of complications and according to the current available evidence, UVCs should be used with caution and an early planned removal is recommended if the clinical indication is no longer present. This strategy is crucial to reduce the incidence of infection and associated morbidity and mortality. If long-term (>4 days) central venous access is required, replacement of the UVC with an epicutaneo-caval catheter (ECC) or with ultrasound-guided central venous access might be beneficial (**Table 2**).

A standardized program for residents on insertion and ultrasound visualization should be implemented in the future. Synthetic and real simulators should be used weekly as has been done for other types of procedures (intubation). Ultrasound training for UVC tip location and tip navigation is quick and can be learned easily. Wireless ultrasound technology can be used during training and in special settings (isolated neonates or delivery room or emergency room).

AUTHOR CONTRIBUTIONS

VD'A, GP, and SR contributed to conception and design of the study. LP organized the database. GB and GP performed the analysis. GP wrote the first draft of the manuscript. VD'A, MP, and GV wrote sections of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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Teamwork and Adherence to Guideline on Newborn Resuscitation—Video Review of Neonatal Interdisciplinary Teams

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Background: Little is known about the importance of non-technical skills for the adherence to guidelines, when teams of midwives, obstetricians, anesthesiologists, and pediatricians resuscitate and support the transition of newborns. Non-technical skills are competences underpinning successful teamwork in healthcare. These are usually referred to as leadership, situational awareness, communication, teamwork, decision making, and coping with stress and fatigue.

Objective: By review of videos of teams managing newborns with difficult transition, we aimed to investigate whether the level of the teams' non-technical skills was associated with the degree of adherence to guidelines for newborn resuscitation and transitional support at birth.

Methods: Four expert raters independently assessed 43 real-life videos of teams managing newborns with transitional difficulties, two assessed the non-technical score and two assessed the clinical performance. Exposure was the non-technical score, obtained by the Global Assessment Of Team Performance checklist (GAOTP). GAOTP was rated on a Likert Scale 1–5 (*1* = poor, *3* = average and *5* = excellent). The outcome was the clinical performance score of the team assessed according to adherence of the European Resuscitation Counsel (ERC) guideline for neonatal resuscitation and transitional support. The ERC guideline was adapted into the checklist TeamOBS-Newborn to facilitate a structured and simple performance assessment (low score 0–60, average 60–84, high 85–100). Interrater agreement was analyzed by intraclass correlation (ICC), Bland-Altman analysis, and Cohen's kappa weighted. The risk of high and low clinical performance was analyzed on the logit scale to meet the assumptions of normality and constant standard deviation.

Results: Teams with an excellent non-technical score had a relative risk 5.5 [95% confidence interval (CI) 2.4–22.5] of high clinical performance score compared to teams with average non-technical score. In addition, we found a dose response like

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association. The specific non-technical skills associated with the highest degree of adherence to guidelines were leadership and teamwork, coping with stress and fatigue, and communication with parents. Inter-rater agreement was high; raters assessing non-technical skills had an interclass coefficient (ICC) 0.88 (95% CI 0.79–0.94); the neonatologists assessing clinical performance had an ICC of 0.81 (95% CI 0.66–0.89).

Conclusion: Teams with an excellent non-technical score had five times the chance of high clinical performance compared to teams with average non-technical skills. High performance teams were characterized by good leadership and teamwork, coping with stress, and fatigue and communication with parents.

Keywords: neonatal resuscitation, patient safety, quality improvement, video, teamwork

INTRODUCTION

The first breath of a newborn initiates the transition from placental dependence to independent life (1). An unsuccessful transition is a high-risk situation and is a significant part of the 2.7 million neonatal deaths per year (2). Improving neonatal care is a global priority and even in high income countries the support of newborns can be suboptimal (3).

The skills to support transition and resuscitate the newborn are essential for every healthcare provider working in the delivery ward. Most newborns adapt well to life after birth. However, some (5–10%) need positive pressure ventilation but only few (0.1–0.3%) receive chest compressions (4). A prerequisite for successful neonatal resuscitation is prompt recognition of signs of a difficult transition and a rapid and relevant coordinated response by the team (5). As the use of more than a few steps in the algorithm of neonatal resuscitation is rare, it is a challenge for healthcare providers to become experienced and deliver a coordinated response. The competences underpinning successful teamwork in healthcare are cognitive, social and personal resources usually referred to as non-technical skills. These skills are described as leadership, situational awareness, communication, teamwork, decision making, and coping with stress and fatigue (6).

All resuscitation teams try to follow current guidelines to produce the best infant outcomes, but performance may fall short of expectations (7). As a result, there is a need for evaluation and educational strategies which include simulation-based training, audit, feedback, and debriefing all of which are facilitated using video review. Little is known about the importance of non-technical skills and interdisciplinary teamwork of resuscitation teams. Video recording such teams (2) to review their performance enables in-depth analysis of non-technical and clinical team performance (1, 8–10). Prediction of a problematic transition and the need for resuscitation may be difficult and as a result, first line personnel including midwives and obstetricians may need to provide resuscitative interventions in the first minutes after birth.

The purpose of this study was to utilize video recording in the delivery rooms to investigate whether the level of non-technical skills in interdisciplinary teams of midwives, obstetricians, anesthesiologists, and pediatricians was associated with the degree of adherence to newborn resuscitation guidelines.

MATERIALS AND METHODS

Study Design and Setting

Real-life video-recordings of newborns were collected from November 2014 to February 2016 at two Danish hospitals; Aarhus University Hospital and Horsens Regional Hospital. Aarhus University Hospital, with ∼5,000 deliveries per year, provides maternal care level III (11) and neonatal care level III (12). Horsens Regional Hospital, with ∼2,000 deliveries per year, provides level II maternal care, and has no pediatric service in the Hospital, but anesthesiologists and obstetricians are trained to provide advanced neonatal life support and work in close collaboration with the neonatal transport team from Aarhus University Hospital who will provide advice and who will send an expert neonatal transport team if needed. The fastest arrival is within 30–45 min after the request.

All 17 delivery suites at the two hospitals were equipped with two or three high-definition mini-dome surveillance cameras and a microphone in the ceiling to cover an oblique view of the room, and the neonatal resuscitation table. Recordings were automatically activated by blue tooth as described previously (13). In case the pregnant woman declined participation no recordings were made. Inclusion criteria were: vaginal birth of a newborn with insufficient response to stimulation, gestational age 35 weeks or more. Duration of the videos included was 9 min. We started the video 2 min before delivery to ensure that raters could assess any preparation before delivery. It was ended seven minutes after delivery no matter how long the video was to minimize potential bias by a longer videoclip, which would allow for altered performance and change of team members. Video was started 2 min before because of maternal problems.

Video Analysis of Non-technical Score

Exposure was the non-technical score obtained by the Global Assessment Of Team Performance checklist (GAOTP) developed by Morgan et al. (14, 15). The GAOTP checklist was selected among several validated tools (16), as it was developed and validated for assessment of non-technical performance of interdisciplinary teams in the delivery room.

The checklist included six dimensions:

1) *Communication with patient/parents*: Excellent team performance was defined as sharing information with the parents and when possible, involving parents in the newborns care.

2) Task/case management: excellent team performance was scored if urgency of the clinical situation was recognized, goals were set and communicated with the team and resources were effectively utilized.

3) *Leadership and teamwork:* excellent team performance was scored if roles were quickly established, a leader was identified, leader encouraged participation and identified opportunities for improvement, and team's roles, and responsibilities were clear.

4) *Situational awareness*: excellent team performance was scored if there was early recognition and a rapid response to a critical situation, if extra personnel were summoned in a timely fashion, and team members remained vigilant, and alert to the clinical situation.

5) *Communication with team members*: excellent team performance was scored if communication was focused with clear questions and instructions directed to a specific person, receiver acknowledged receipt of message and confirmation that requested actions was completed.

6) *Environment of the room:* excellent team performance was scored if the environment was orderly and controlled, voices remained calm and focused, no sign of stress or fatigue among team members.

Each of the six dimensions were rated by a Likert scale 1–5. GAOTP overall score was the mean score on a Likert scale, where "*1*" was a poor non-technical score, "*3*" was an average non-technical score, and "*5*" was an excellent non-technical score (**Supplementary Material 1** Description of GAOTP dimensions). Two physicians (authors LB, KRH) experienced in the use of GAOTP assessed all the videos using the GAOTP checklist. All videos were rated by both reviewers blinded to the other reviewer's ratings (13).

Video Analysis of Clinical Performance

The primary outcome was the teams' clinical performance score assessed according to adherence of the European Resuscitation Counsel (ERC) guideline for neonatal resuscitation and transitional support. In both hospitals all healthcare providers in the Labor and Delivery units (midwives, obstetricians, anesthesiologists, and pediatricians) were trained by the ERC guideline. As the guideline was updated during the study, both the more recent and the previous guideline was accepted as part of our checklist, e.g., in the assessment of heartrate we accepted any assessment as there was no specific recommendation for heart rate measurement in the 2010 guideline and the 2015 guideline recommended this be changed to a 3-led electrocardiogram. The ERC guideline was adapted into the checklist *'TeamOBS-Newborn'* to facilitate a structured and simple performance assessment (17, 18). The checklist TeamOBS-Newborn consisted of seven categories each with a number of items to be ticked off. The Categories were: (1) *Preparation of equipment and room*, 9 items; (2) *Initial assessment and support of transition*, 7 items; (3) *A-problems*, 5 items; (4) *B-problems*, 4 items; (5) *C-problems*, 4 items; and (6) *Global score*. The raters assessed all items according to the ERC guideline in three levels: 0 points (not done or done incorrectly), 1 point (done partially or not done in a timely manner) and 2 points (done correctly and in a timely manner). We also included the category *Cannot be assessed* or *not indicated* (e.g., if an IV line was not indicated) (no value). The score of each item was then multiplied by the assigned weight of the item and totaled to give a weighted score, i.e., a percentage of the highest possible score [a maximum of 58 if all items were assessed, but less if one or more items were marked as *Cannot be assessed* or *Not indicated*]. To assess 'high clinical performance' we used the ERC guideline ("checklist") as one of two parts of the evaluation. The second part of the evaluation was a global score of patient safety introduced in order to allow the experienced raters to provide the team with a numeric score from 0 to 100 on a visual analog scale; with 100 reflecting best expert standard. The TeamOBS-newborn tool resulted in a clinical performance score from 0 to 100, where low clinical performance was 0–59, average clinical performance was 60–84, and high clinical performance was 85–100 (**Figure S1**). Two experts in neonatology (TBH and GE) assessed all videos independently by use of the checklist and were blinded for each other's ratings.

None of the raters were involved in the delivery or the management of the newborn.

Ethics and Legal Aspects

All videos were included following informed consent in conformity with the Danish penal code §264. Gaining informed consent during labor was not acceptable according to the Danish Health Act §43–44. Women were informed about the research project TeamOBS during antenatal visits. All women who planned to give birth in one of the two Labor and Delivery wards were informed between gestational week 18–28 by oral and written information provided by a sonographer or a midwife. Whether the woman accepted or denied participation was noted in her medical record. If participation was declined cameras were inactivated. If participation was accepted the cameras were activated automatically by staff's mobile devices if resuscitation of the newborn was initiated. The use of any recording should be approved within 48 h after delivery by all persons present in the room; i.e., the woman giving birth, her husband or any other person she had asked to be present, and all healthcare providers. If written consent was missing from one person the video was automatically deleted. The research project TeamOBS was approved legally and ethically in May 2014 by the Central Denmark Region, the Danish Data Protection Agency (2012-58-006) and the Research foundations of central Denmark (1-16-02-257-14).

Statistical Analysis

Agreement among raters was identified by the intraclass correlation (ICC) and Bland-Altman analysis (19). The non-technical score was also analyzed by category by Cohen's kappa weighted and percentage agreement (20). The association between the non-technical score and clinical performance was described using a restricted cubic spline regression analysis with three knots at 2.5, 3, and 3.5 on the non-technical score (21). The mean difference and relative risk in clinical performance between the lowest "*3*" and the highest non-technical score "*5*" was estimated using spline regression analysis. The risk of high and low clinical performance was analyzed on the logit scale to meet the assumptions of normality and constant standard deviation (22). 95% confidence intervals (CI) were calculated by non-parametric percentile bootstrap. Regression models were checked using diagnostic plots of residuals, and two-sided $p <$ 5% were considered statistically significant. We conducted all statistical analysis by STATA 15 (Stata Corp LP, College Station, TX, USA).

RESULTS

Included Videos

From November 2014 to February 2016, we informed all women, expecting to give birth at one of the study hospitals about the research project. Consent was declined by few healthcare providers, mothers, or relatives. We included 43 videos of teams managing newborns. Of these, 58% of the newborns received continuous positive airway pressure (CPAP), 28% received five inflations breaths, 23% were suctioned, and 2% received chest compressions and 42% needed no further intervention.

Inter-rater Agreement

Raters assessing non-technical skills achieved an ICC of 0.88 (95% CI 0.79–0.94); the neonatologists assessing clinical performance achieved an ICC of 0.81 (95% CI 0.66–0.90), **Table 1**. Agreement among raters assessing non-technical skills, on single item level, was 0.82–0.90 weighted Kappa and agreement was visualized by Bland Altman Plots and limits of agreement (**Table S1, Figure S2**).

Non-technical and Clinical Performance

Teams with low and average clinical performance (clinical performance < 85) often had a lower score due to the use of CPAP to a newborn who was judged by the experts to have no need or due to delayed assessment of the newborn's heartrate. The clinical performances and the non-technical score were correlated and showed a dose-response like association (**Figure 1**). Thus, an excellent non-technical score was associated with a high clinical performance (adherence to guideline score ≥ 85) of 86.5% (95% CI 68.7–97.5%) compared with 15.6% (95% CI 3.8–30.7%) for an average non-technical score (**Table 2**). This corresponded to a RR 5.5 (95% CI 2.4–22.5) of high clinical performance in teams with an excellent compared to an average non-technical score.

High performing teams demonstrated excellent team behavior in the non-technical dimensions: leadership and teamwork, coping with stress and fatigue, and communication with the newborn's parents. The mean differences are listed in **Table 3** and the association of individual non-technical categories and clinical performance are visualized in **Figure S3**. There was no significant difference in teams' clinical performance between the two hospitals and no differences by time of day (day shift, evening shift, and night shift).

DISCUSSION

Teams with an excellent non-technical score had five times more likely to have a high clinical performance than teams with an average non-technical score. The clinical performance and the non-technical score were strongly correlated with a dose-response like association. High performing teams demonstrated excellent team behavior in leadership and teamwork, coping with stress and fatigue, and communication with parents.

The main strength of this study was that evaluation of the management of difficult transition was based on real-life video recordings of teams of midwives, obstetricians, anesthesiologists, and pediatricians managing newborns. The technical solution was also a strength as our automated activation of cameras ensured enrolment of videos both day and night. Another strength was the systematic video analyses as four trained raters assessed all videos independently by use of structured and validated checklists and a high interrater agreement (23).

The study was somewhat limited by the small number of videos, which reduced the possibility of performing sub-analyses, e.g., related to team construction, or level of newborn life support needed. However, to optimize learning from this study we insured that only newborns thought to be in need of transitional support or resuscitation participated in the study. We believe, that our study population corresponded to a random sample of the entire population of newborns with similar needs.

Concerning the internal validity, we cannot exclude that teams that perceived their own performance as suboptimal were more prone to deny participation. Furthermore, the TeamOBS-newborn was not validated *a priori*. However, it was developed by stringent use of the detailed version of the current ERC guideline and the inter-rater agreement was high (24). Furthermore, it was impossible to blind raters of the clinical performance to the team's non-technical score and vice versa. However, the use of several raters and checklists limited this problem, and all raters were blinded to the other raters scores. Finally, our study found that clinical performance and the non-technical score was strongly

TABLE 1 | Inter-rater agreement for clinical performance and non-technical performance.

	Descriptive		ICC (95% CI)			
	Mean	Range	Individual rater*		Average of two raters**	
Non-technical score GAOTP	23	(12–30)	0.79	(0.65–0.88)	0.88	(0.79–0.94)
Clinical performance: TeamOBS-newborn	81	(28–100)	0.69	(0.49–0.82)	0.81	(0.66–0.90)

*Intraclass correlation (ICC) between one rater and the other.

**All 43 videos were analyzed by 4 raters, 2 for non-technical, and 2 for clinical performance.

correlated with a dose-response like association. However, this is not a proof of causality.

This study and prior studies demonstrated that video can capture teams' behavior, timing of procedures, and the flow of an algorithm and can be reviewed repeatedly (8). This information can be difficult for the healthcare providers to recall after the management of an emergency, and studies have found written documentation in the patient files may be misleading when compared to videos (25, 26). However, due to the requirements of informed consent and legal concerns, videos are used rather rarely in clinical practice even though it was already introduced in 1969 (27–29). We addressed this challenge by informing all women who planned a vaginal birth before delivery.

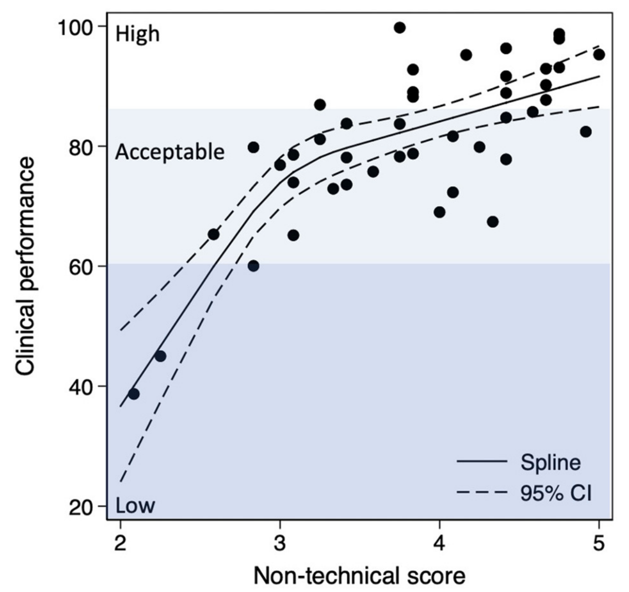

FIGURE 1 | Non-technical score and clinical performance is visualized by spline regression analysis.

Research in non-technical skills described as leadership, situation awareness, communication, teamwork, decision making and coping with stress and fatigue have revealed that the importance of these specific skills differs among settings, tasks and specialities e.g. between *ad hoc* teams for resuscitation and surgical teams conducting planned procedures (30–32). Thus, team communication, task management and leadership were fundamental for team adherence to guidelines in a setting where pediatric teams managed 132 newborns delivered by planned cesarean section (10). The majority of these newborns were healthy. A sub-analysis of the 12 resuscitated newborns found that early recognition and a rapid response, situational awareness, was critical for good clinical performance (9). These findings differed from our results with respect to specific skills as we found leadership, teamwork, and coping with stress and fatigue to underpin high clinical performance. Our interdisciplinary teams dealt with unplanned emergency situations in vaginally delivered newborns only, which may explain the differences in importance of specific skills. Interestingly, we found that coping with stress and communication with the parents was associated with high clinical performance score. We speculate that

TABLE 2 | Chance of clinical performance according to the level of non-technical performance.

Non-technical score	Risk of low clinical performance (95% CI)*		Chance of high clinical performance (95% CI)**		RR for high clinical performance (95% CI)****	
2 (poor) (%)***	94.4	(47.3–99.6)	0.01	(<0.01–2.5)		
3 (average) (%)	14.7	(6.2–25.2)	15.6	(3.8–30.7)		
4 (good) (%)	1.4	(0.1–3.7)	54.8	(40.6–66.7)	1.5	(1.3–2.0)
5 (excellent) (%)	<0.01	(<0.01–1.0)	86.5	(68.7–97.5)	5.5	(2.4–22.5)

**TeamOBS-newborn score below minimal pass (score > 60%).*
***TeamOBS-newborn score above high performance (score ≥ 85%).*
****Limited data for the score of 2 (see **Figure 1**).*
*****Reference group average (3) non-technical score.*

TABLE 3 | Mean difference in clinical performance between non-technical score 5–3.

	Non-technical score (3)		Non-technical score (5)		Mean difference	
	Mean	95% CI	Mean	95% CI	Diff	95% CI
1. Communication with parents	75.9	(66.4–83.7)	88.1	(83.3–91.8)	12.1	(1.9–22.4)
2. Task management	82.5	(72.3–72.3)	87.7	(82.2–92.0)	5.3	(−5.4–15.9)
3. Leadership and teamwork	82.0	(76.1–86.9)	93.0	(87.2–96.8)	11.0	(3.0–19.0)
4. Situational awareness	77.9	(62.8–88.7)	85.8	(80.9–89.8)	7.9	(−6.1–21.9)
5. Communication with team members	81.5	(74.3–97.3)	90.3	(83.8–94.9)	8.9	(−0.7–18.4)
6. Environment, coping with stress, and fatigue	69.3	(58.0–79.0)	90.7	(87.4–93.4)	21.4	(9.8–33.0)
Summative non-technical score (GAOTP)	74.3	(67.3–80.4)	92.8	(88.7–95.9)	18.5	(10.0–27.0)

communication with parents may be a proxy variable also covering overview, self-confidence and clinical performance superiority, and communication with parents may not be prioritized if the team is coping poorly with stress and fatigue (33).

Clinical performance was in our study assessed by adherence to guidelines for neonatal resuscitation and transitional support. Recent studies have demonstrated that performance may fall short of expectations as only 20–25% of highly educated teams managed neonatal resuscitation with full adherence to the guideline (34, 35). In our study 51% of the teams achieved a high clinical performance defined by a score of 85–100, i.e., a rather different outcome. Evaluation of clinical performance in low resource settings in both Africa (36) and Nepal (37, 38) has also been conducted, however these studies differ from our study as they only evaluated video without any sound track.

Performance is likely to differ between centers (39). However, training of staff in the two hospitals included in the current study were led by the same team from Aarhus University Hospital, and all staff were trained using ERC guidelines and similar equipment. Still, there may be differences by staff and center, but our study sample failed to allow stratification by center or team composition.

Lower scores in our study were often related to delayed or no verbalization of the newborns heart rate and to the use of unnecessary CPAP according to the raters. Verbalization of the newborns heart rate is vital for the team performance, as the management depends on this information. In teams with lower scores the heart rate was often assessed late or not at all. Both hospitals trained all healthcare providers in neonatal resuscitation in simulation-based setup using a Laerdal Resusci baby®, which cannot simulate the heartrate. Therefore, the instructor provided this information by talking to the room as the "e.g., heartrate is 55" when the team asked for the heartrate. Hereby we may have introduced negative learning, as the teams never trained to assess the newborns heart rate. This must be addressed in the training programs. Furthermore, CPAP should only be given if medically indicated. In teams with lower scores, CPAP was often given without indication and for prolonged periods. Therefore, future training programs should focus both on when to initiate CPAP treatment and when to discontinue the treatment.

In the clinical setting, real life videos may be used for feedback, debriefing, quality assurance, and for identification of important focus areas for training programs or possible adjustments of training programs. For neonatal resuscitation, video has been used to identify the errors and inappropriate team behavior and to train teams to overcome these difficulties (40–42). However, this has never been shown to improve neonatal outcome (43). Another study including pediatric teams used video-based debriefing to improve adherence to guidelines (44) and found it lead to improved adherence to guidelines. Both studies investigated teams of pediatricians and future research should investigate how we can improve performance for interdisciplinary teams of midwives, obstetricians, anesthesiologists, and pediatricians on the delivery ward.

CONCLUSION

By using video recordings in the delivery room, we assessed interdisciplinary *ad hoc* teams of midwives, obstetricians, anesthesiologists, and pediatricians and found that teams with an excellent non-technical score had a five times higher chance of high clinical performance compared to teams with an average non-technical score. We also found a dose-response like association between non-technical score and clinical performance. This was mainly driven by leadership and teamwork, coping with stress and fatigue. Future research should investigate how we can improve clinical performance and leadership, teamwork and coping strategies for stress and fatigue to ensure high clinical performance.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The research project TeamOBS was approved legally and ethically in May 2014 by the Central Denmark Region, the Danish Data Protection Agency (2012-58-006) and the Research foundations of central Denmark (1-16-02-257-14). The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

LB, LH, GE, NF, NU, OK, TH, and TM contributed to conception and design of the study. LB, LH, and OK contributed to data collection. LB, KH-H, TH, and GE assessed the videos. LB, NU, and TH contributed in data analysis. All authors contributed to the writing of this work. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

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Preparing for Pediatrics: Experiential Learning Helps Medical Students Prepare for Their Clinical Placement

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Despite the importance of effective communication skills in pediatrics, clinical placements may inadequately prepare undergraduate students to communicate with children. The integration of non-clinical interactions with healthy children within a pediatric curriculum has the potential to enhance learning. We designed and implemented a novel course involving experiential learning, including video-recorded consultations with simulated parents (SPs), team-based scenarios with a pediatric mannequin, interactions with healthy children through a pre-school visit and medical student led health workshops for primary school children. Medical students at the RCSI University of Medicine and Health Sciences took part in the course. We used a mixed methods approach to assess the impact of the course. We investigated medical students' perspectives through a pre- and post-intervention questionnaire and post-intervention focus group discussions (FGDs). We assessed participating children's health literacy at the start of the course. 144/279 (51.6%) of the fourth year medical student cohort on their pediatric rotation, consented to participate in the study. All 144 (100%) of consenting students completed the pre-intervention questionnaire. 59/144 (40.1%) of consenting students completed the post-intervention questionnaire. Results showed a statistically significant improvement in ratings ($p < 0.05$) for items related to managing a confrontational situation involving family members, completing a psychosocial assessment with an adolescent and effectiveness using evidence-based medicine (EBM) when motivating patients. There was a statistically significant decrease in how students rated their comfort at using EBM when motivating patients. Four themes relating to how students experienced the intervention were identified from eight FGDs ($n = 35$ students): Shaping Student Learning; Supporting Student Learning; Developing New Skills and Feeling More Prepared. 39/49 (79.6%) children completed a health literacy assessment. All questions had a high percentage of positive responses. Question 7, understanding your doctor, had the highest proportion of negative responses (27%). Ours is one of the first studies to design an educational intervention to enhance pediatrics teaching by combining interactions with healthy children outside of a clinical setting with more traditional simulation-based approaches. We conclude that this type of intervention supports students' learning of pediatric communication skills and enhances students' perceived preparation for clinical placement.

Keywords: pediatrics, communication, simulation, experiential learning, simulated patient

INTRODUCTION

Despite the importance of effective communication in pediatrics (1), clinical placements may inadequately equip undergraduate medical students with the opportunity to learn effective pediatric communication skills (2). During clinical placements, interactions with children are often observational (3), meaning that most students have only limited interactions with children unless they are involved with children in external activities or through families and friends. While medical students are often eager for real patient contact, when presented with such opportunities through clinical placements they can find the transition abrupt (4). The start to clinical placements can be unpleasant for students due to their lack of knowledge related to specific specialties, their role and the new environment (5). Furthermore, medical students experience additional struggles related to frequent changes in staff and difficulties applying knowledge in practice (6). Some of these challenges are common across all clinical placements, others are unique to a specific specialty (7). Those unique to pediatrics relate to the significant variability in how consultation skills are taught during pediatric clerkships (8) and the aspects of pediatric communication skills which add additional complexity such as the triadic nature of the consultation between the child, the parent or caregiver and the doctor and the different communication strategies required for children of different developmental stages (9). While observational learning can be effective (10), students must draw on certain attributes such as self-regulation, self-efficacy and insight. If students lack these skills and do not have the required knowledge to make sense of this observational learning, are students potentially missing out on rich learning opportunities?

Communication skills training has the potential to bring significant benefits not only to participants but also to their patients and families (3). To be effective, students must develop the unique skills to communicate with children and have opportunities to practice in settings that do not interfere with patient care (2). Experiential learning represents an ideal setting for communication skills training (11). The main theoretical underpinning for experiential learning is Kolb's Experiential Learning Cycle (12). This model includes four stages: (a) concrete experience: actively participating in an experience; (b) reflective observation: reflecting on the experience; (c) abstract conceptualization: translating the reflections to learnings; and (d) active experimentation, trying out what has been learned (12). This theory focuses on learning from one's own concrete experience and does not address learning that occurs through observation of other learners' experiences. More recent theories highlight the value of vicarious experiential learning, or learning through the observation of others' in action (14). In simulation-based learning, when learners are observing peers, their observations should be structured through the use of tools to optimize learning (15), perhaps a feature of observational learning which could also be transferred to observations in the clinical setting. Therefore in experiential learning settings, learning is most effective when learners both participate themselves and engage in structured observation of their peers.

While pediatric clerkship directors believe simulation-based education meets teaching requirements, they also have a number of concerns, including: (a) barriers to its implementation such as funding, available faculty time, technical support, lack of simulation trained faculty and availability of physical space, and (b) appropriateness of replacing real experiences with simulated experiences (16). While experiential learning in healthcare education often focuses either on simulation-based or workplace-based learning, we see additional scope to enhance experiential learning with the inclusion of real interactions outside clinical settings. Challenges exist however concerning the involvement of children as laws prohibit the employment of children in the same format as adult simulated patients. While medical programmes have successfully integrated children as patients into pediatric teaching and assessment and shown positive outcomes for both the children and learners, ethical concerns remain (17). Recommendations suggest limiting this type of involvement to assessments that cannot be carried out by other means (18). Partnerships between a school and a university can provide a solution in the context of pediatric skills (19) where an intervention is designed in such a way that it is mutually beneficial to both students and children.

We hypothesized that providing experiential learning experiences for students outside the clinical setting, through simulation and community engaged learning has the potential to better prepare undergraduate medical students for their pediatric clinical placements. To this end, we designed and implemented a novel course that integrated simulation-based learning and interactions with healthy children through student led health and well-being workshops. Our aims were to explore the impact of these learning experiences on medical students' development of pediatric communication skills and their preparedness for clinical placement as well as the impact of the workshops on the children's health literacy.

TABLE 1 | Course elements and learning outcomes.

Course Element	Learning Outcomes
Recorded simulated parent consultations (without a child present) with multi-source feedback (self, tutor and simulated parent)	Demonstrates the ability to accomplish the specific tasks of an effective consultation. (i) Establishes and builds a relationship (ii) Initiates the consultation and sets the agenda (iii) Establishes, recognises, and meets patient needs (iv) Gathers information (v) Explains the diagnosis and plans and negotiates management plans (vi) Structures, and prioritizes the consultation (vii) Closes the consultation and establishes future plan
A health and well-being workshop delivered by the medical students to local primary school children (aged 7–9 years)	Demonstrates the ability to convey specific explanations related to health promotion and EBM in an age appropriate manner Establishes and builds a relationship
Team based simulated scenario with a pediatric mannequin, which was live streamed for peer learning	Demonstrates the ability to take a systematic, problem-focused medical and surgical history and interpret the relevant clinical findings Interprets and integrates the history, findings of physical examination, results of laboratory tests and imaging studies, and other relevant data to arrive at an appropriate diagnosis or differential diagnosis Demonstrates effective communication skills with members of the health care team
A pre-school visit to observe children at different levels of development (aged 6 months to 4 years)	Demonstrates age appropriate communication skills for children of different developmental stages Identifies the normal developmental milestones and differences in children's stages of development

METHODS

Development of the Novel Pre-clinical Course

The experiential learning week was held in the RCSI SIM Centre for Simulation Education and Research. The teaching had taken place for the first time in the 2018/2019 academic year, and the study took place during the second year of the teaching in the 2019/2020 academic year. The course represented the refinement of an existing curriculum based on feedback from previous students and an assessment of knowledge gaps identified during previous clinical assessments. Common deficits identified within the communication portion of the clinical examination informed this educational innovation for teaching communication skills. We aimed to minimize didactic teaching and emphasize active student engagement.

The 5-day course was designed to be placed at the start of the 7-week pediatric clinical rotation. See **Table 1** for an overview of the experiential learning elements and respective learning outcomes. The aim was to give students experience with the basic skills they would need for placement and to ensure exposure to all the required elements even if experiences on placement differed. The week involved multiple teaching modalities, however, it was the four experiential learning elements which were the focus of this study. These were recorded simulated parent (SP) consultations, medical student led health and well-being workshops, team-based scenarios with a pediatric mannequin and a pre-school visit (see **Table 1**). The main aim was to foster appropriate communication skills for varying contexts including other healthcare team members, children and their families and carers. The students participated in the SP encounters on day 2, the health and well-being workshops on day 3 and team-based simulations on day 4. As the pre-school could only accommodate a small number of students at a given time, students attended the pre-school on day 2 or day 4 depending on the time they were allocated.

Experienced pediatric faculty had written the SP cases and the team-based simulation scenarios the previous year and the same scenarios were used in the teaching. See **Appendix A** for details of the cases and scenarios. All SPs who participated in the teaching had completed RCSI simulated patient training (**Appendix B**). Their case was emailed to them 4 days before the teaching. They were given the opportunity to clarify details on the day. Each scenario lasted 8 min and was followed directly by 2 min of verbal feedback from the SP to the student. The scenarios were video recorded using a web-based audio-visual recording and learning platform (CAE Learning Space, Sarasota, Florida). Immediately after the consultation and verbal feedback, the SPs entered feedback on the learning platform using the Consultation and Relational Empathy (CARE) measure (20). Students were in groups of three or four. They participated in one consultation individually and then watched their peers. Afterwards students watched back their own video and rated themselves on the learning platform using a subset of questions from the Pediatric Consultation Skills Assessment Tool (PCAT) (1) (**Appendix C**). Faculty also rated the students' videos with the PCAT. Students were given access to the faculty and SP ratings through the learning platform on completion of their self-rating.

Since teaching took place outside the clinical setting, it was important to integrate direct experience with children. Given ethical challenges with the involvement of children as simulated patients, we explored other means of providing opportunities for medical students to engage with children. We created opportunities in two ways across two different age groups. By partnering with two local schools, we created a community engaged learning experience (21) which was mutually beneficial to both medical students and children. We organized medical student led health and well-being workshops

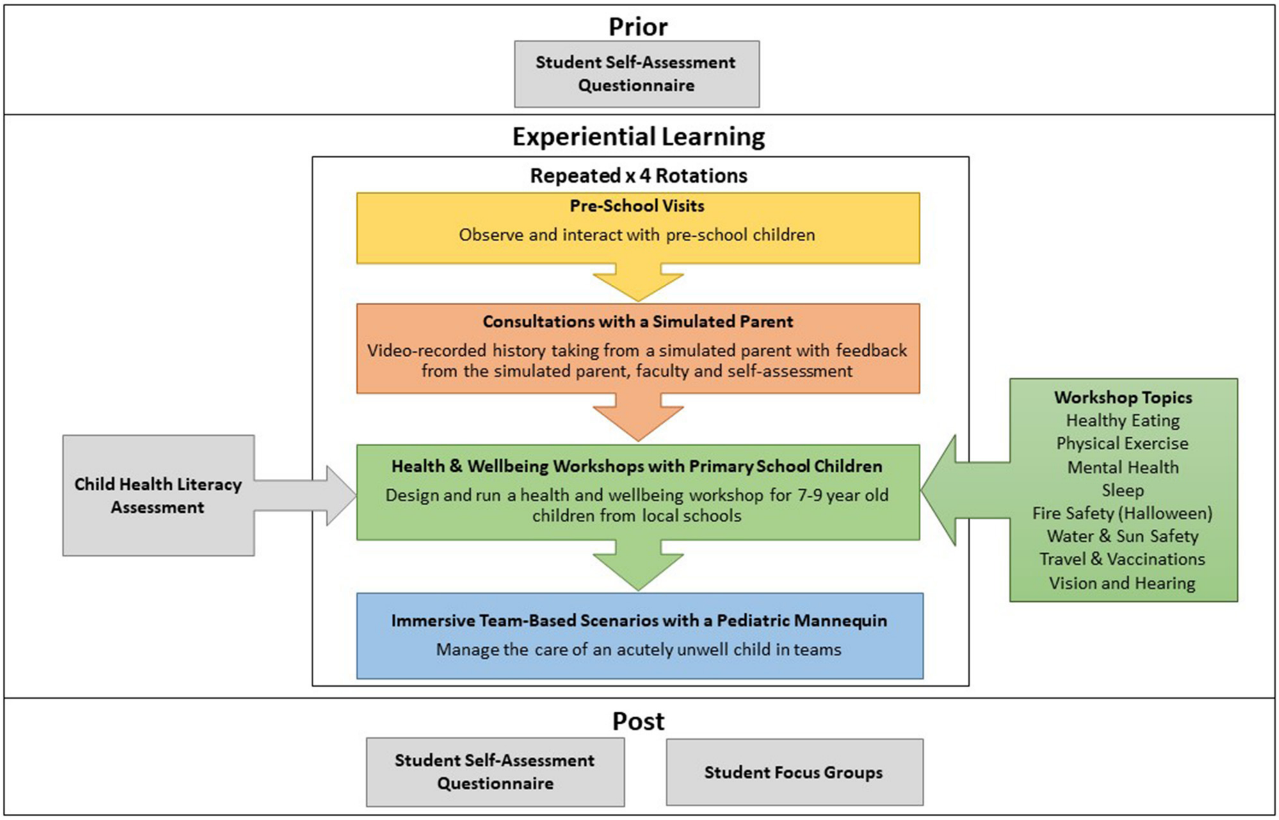

FIGURE 1 | Overview of intervention and data collection.

for primary school children (aged 7–9 years). The schools proposed health-related topics that would be relevant to the children. Through the workshop delivery, medical students had the opportunity to learn how to explain health-related topics at the appropriate development stage for children, in language they could understand. The children had both the opportunity to learn about health and well-being and the opportunity to attend third level campus regularly. Familiarization with a third level campus improves access to higher education by breaking down barriers and allowing the children to interact with university students and staff (21). The day before the workshop, students were briefed on their role, divided into groups, given guidelines regarding the format and topic of the workshop and provided with a lesson plan template. Medical students were encouraged to make the workshops interactive and choose from arts and crafts, equipment and technology to support the workshop. The following day, in advance of the workshop, faculty reviewed the appropriateness of students' plans. The children attended the RCSI SIM Center for Simulation Education and Research with their teachers and were divided into small groups of four to six with the medical students (ratio of 1:2 or 1:1 medical students to children). Teachers, community engagement staff, pediatric faculty and simulation staff were present at all times but gave minimal input to the workshops once started. The 90 min workshop included a fruit break after 45 min.

During the team based simulations, students worked in groups of three to manage an acutely unwell child. One faculty member controlled the parameters of the pediatric mannequin (Gaumard Super Tory Mannequin) in a separate control room and acted as an embedded participant for telephone calls. A second faculty member acted as an embedded participant in the role of a nurse within the treatment room. The session was live streamed to students watching in another room. Students participated in one scenario and watched three others. Each scenario lasted ∼15 min and was followed by a 30 min group debrief with faculty immediately after. Debriefings included feedback on team communication and decision-making and addressed students' specific questions about medical care.

To give students a chance to interact with younger children and to understand the stages of development, we arranged a visit for the students to a local pre-school (aged 6 months–4 years). During this visit, we provided students with a worksheet of prompts regarding the different domains of development to help structure their observation of the children. We also encouraged them to discuss their observations with their peers.

The teaching week was repeated five times throughout the year to cover all five rotational blocks of students. Each block was further subdivided into two groups, so the teaching was repeated twice in each block. The fifth rotation was excluded from

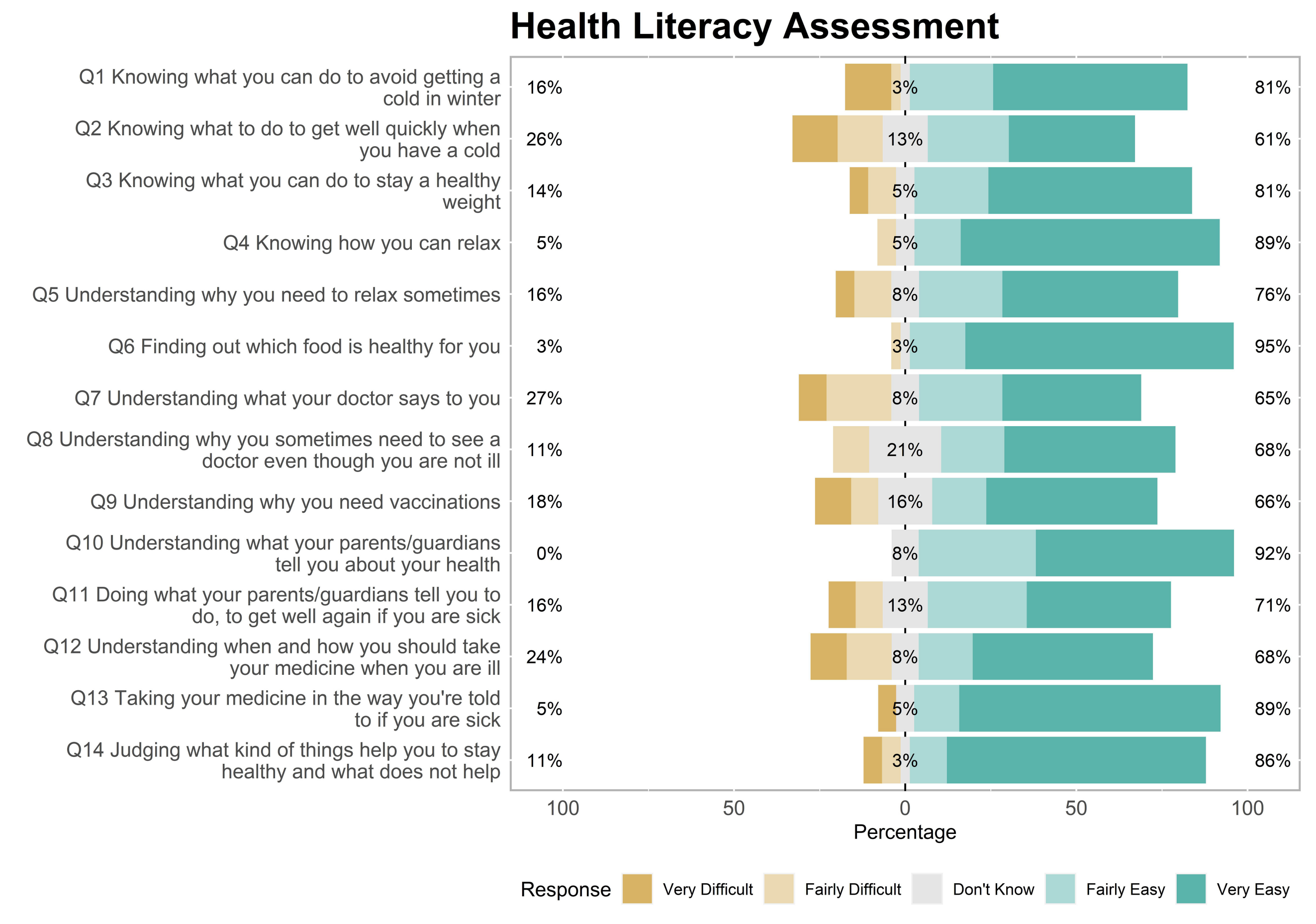

FIGURE 2 | Responses to health literacy assessment.

analysis since it had significant modifications due to restrictions on educational activities as a result of the COVID-19 pandemic.

Evaluation of the Impact of the Course

This cross-sectional mixed methods study, explored the learning experience of students participating in pediatric teaching during the 2019/2020 academic year.

We conducted a mixed methods analysis of the medical students' perspectives of pre-clinical experiential learning using focus group discussions (FGDs) and a questionnaire administered before and after the intervention. A mixed methods approach is particularly useful when studying complex initiatives and can also allow for the better application of findings (22). Kolb's experiential learning theory (12), as well as theories on vicarious experiential learning (14) were used as sensitizing concepts in the analysis due to their relevance in explaining the learning processes in experiential learning settings. Our aim with the FGDs was to understand how students learned from the experiential learning elements of the course and in what ways the course impacted their perspectives toward their pediatric clinical placement. The pre-post questionnaire was self-assessed to help us understand the change in students' perceived abilities as a result of the course. Better understanding of what aspects of the intervention students found effective for learning would allow us to further adapt and improve the teaching.

We also assessed participating children's health literacy at the start of the course. We planned to complete the health literacy assessment at the end of the course but the immediate shut down of education at the start of the COVID-19 pandemic meant this was not possible. The study was approved by the Royal College of Surgeons in Ireland (RCSI) research ethics committee REC001719.

Participants

Study participants were undertaking their pediatric clerkship during their penultimate year in the medical school at RCSI. All medicine programmes (undergraduate 5 and 6 year, graduate entry 4 year) are together at this point. All medical students attending the pediatric rotation were eligible to participate in the research and all students received the teaching intervention regardless of participation in the research. Convenience sampling was used.

Through the Recreation Education And Community Health (REACH) RCSI Programme, the university community engagement and access programme, children from two local schools were invited to participate in the workshops. The schools were DEIS schools (Delivering Equality of Opportunity in Schools), identified as educationally disadvantaged by the Department of Education in Ireland. Children were in third class of primary school. All children in the invited classes participated in the workshops regardless of participation in the research.

Data Collection

We collected various forms of quantitative and qualitative data (see **Figure 1**). Before and after the intervention students completed a questionnaire about their perceived ability/knowledge in certain areas of pediatrics (23) (**Appendix D**). We held FGDs with students at the end of each teaching week. FGDs were selected for the collection of qualitative data as these have become a method of choice for assessing programmes (24). The FGDs were between 30 and 45 min long and were conducted by the lead researcher (CS) who supported the programme but was not in involved in grading the students. Another researcher (CM) was also present who managed consent and took field notes. See **Appendix E** for the interview topic guide. The FGDs were audio recorded, transcribed and de-identified.

Children who participated in the health and well-being workshops and who gave consent (both parent/guardian consent and child assent) were asked to complete a health literacy assessment at the start of the intervention. The health literacy assessment was based on the European Health Literacy Survey adapted for this age-group (25). While the tool had been validated only in the German language, an English translation was available and was used due to the lack of other suitable tools available at the time. The language in the English translation was reviewed by the research team, including the lead researcher (CS), the community engagement manager (MK) and a pediatric tutor (DOL). The school teachers were also asked if they thought the language was suitable for their class groups. Finally, the instrument was piloted with a small number of children not involved in the study to test for readability in the relevant age group. Following this process, a revised version of the tool was created and used for data collection (**Figure 2**). The main changes included; re-ordering the questions so that related items were beside each other; changing the format of the question from "How easy or difficult is it for you to ..." to "Do you find each of the following easy or difficult?" and removing the question "stick to what you have learned in road safety lessons or the safe cross code?", as this was not directly related to health.

Data Analysis

Quantitative Data Analysis

Statistical analysis was conducted using the statistical package R (R Core Team, 2019, Vienna, Austria). Pre and post intervention questionnaire responses were compared using the paired sample Wilcoxon signed rank test with Bonferroni adjustment (26). Descriptive statistics were used to summarize the children's responses to the health literacy assessment completed at the start of the intervention.

Qualitative Data Analysis

Data were analyzed using thematic analysis (27). Data were coded inductively using the theories of experiential and vicarious learning as sensitizing concepts. Preliminary data coding was performed by two researchers (CS and MA). CS was experienced in coordinating simulation-based education (SBE) and MA was an undergraduate medical student who had not participated in the intervention. The addition of a medical student to the research team aimed to include the student perspective. After initial familiarization with the data, first-level coding was completed independently by two of the researchers on the first two FGDs. CS completed analysis using NVivo (QSR International Pty Ltd., 2018, Version 12) and MA used Microsoft Word and Excel. After the preliminary coding, CS and MA met with two experienced simulation educators (CC and WE), one with significant expertise in qualitative research (WE), to review the analysis and refine the codebook through discussion to achieve consensus. The two researchers then coded the remaining six FGDs using the codebook before meeting again to discuss any new codes and to carry out second-level coding by agreeing on the grouping of codes into themes. The researchers ensured reflexivity by reflecting on the influence of their knowledge and experience on the analysis. Of note, in addition to expertise in simulation and qualitative research, WE is an experienced pediatric emergency medicine physician. The research team enhanced the credibility of the findings by ensuring their relevance and applicability to the teaching and by extracting quotes to illustrate main themes (28).

RESULTS

Pre–post Questionnaire

Two hundred and seventy nine medical students across the four included rotation blocks completed the full course as it was a mandatory part of their pediatrics teaching. Of the 279 students, 144/279 (51.6%) of them consented to participate in the study. The 144 consenting students were across all four included rotations: 47 from the first rotation, 34 from the second rotation, 45 the third rotation and 18 from the fourth rotation. Students who consented to participate received the pre-post questionnaire and were invited to a FGD. All 144 (100%) of consenting students completed the pre-intervention questionnaire. 59/144 (40.1%) students completed the post-intervention questionnaire. Of the 59 who complete both pre and post-intervention questionnaires, 10 students were from the first rotation, 14 from the second rotation, 22 from the third rotation and 13 from the fourth rotation.

The median and inter-quartile range for all except one question on the pre-intervention questionnaire were the same for the 144 cohort of students as for the subset of 59 students. Item seven was the only item which differed, having a median of 6 for the full group of 144 and a median of 5 for the subset of 59 students, however, the interquartile range was the same for both groups (4–7). As the responses of the subset of students were similar to that of the larger group, and to allow for pairwise comparison, further analysis was carried out only on

TABLE 2 | Pre- and Post-intervention questionnaire results comparison.

	Pre-intervention	Post-intervention			Overall Delta	Rt1 Delta	Rt2 Delta	Rt3 Delta	Rt4 Delta
Question	**Median (IQR) ($n = 59$)**	**Median (IQR) ($n = 59$)**	***p*-Value**	***p*-Value (adj)**	**Median ($n = 59$)**	**Median ($n = 10$)**	**Median ($n = 14$)**	**Median ($n = 22$)**	**Median ($n = 13$)**
1	6 (5–8)	7 (6–8)	0.04	0.34	1	0	1	1	−1
2	6 (5–7)	7 (6–7)	0.09	0.79	1	−0.5	1	1	1
3	5 (3–6)	6 (4–7)	0.007	0.06	1	0	1	1	2
4	5 (3–6)	6 (5–7)	0.001	0.01*	1	0	1	1	3
5	3 (1–5)	6 (4–7)	0.000004	0.00003*	2	2	2	2	3
6	3 (1–5)	4 (1–6)	0.10	0.83	0	0	1.5	0	1
7	5 (4–7)	3 (1–6)	0.0004	0.003*	−2	−1	−0.5	−2.5	−2
8	5 (4–6.5)	7 (6–8)	0.00004	0.0003*	1	0	1.5	2	1

IQR = (1st, 3rd interquartile range).
p-Value presented from the two sided Wilcoxon Sign Rank Test for paired data, pre and post intervention.
p-Value (adj) presented is the Bonferroni adjusted p-value for 8 tests.
**Significance values at the level of $p < 0.05$.*
Delta represents the median of the difference in score between post and pre.
Note that the median of the differences (Overall Delta) is not the same as the difference of the medians (Post-intervention Median minus Pre-intervention Median) in skewed data.
Rt represents the rotation grouping.
Questions from Whitt et al. (23).
Q1. Please rate your comfort level in communicating with parents and family members of young children.
Q2. Please rate how effective you are at communicating with parents and family members of young children.
Q3. Please rate your comfort level in managing a confrontational situation involving family members with differing opinions.
Q4. Please rate how effective you are at managing a confrontational situation involving family members with differing opinions.
Q5. Please rate your comfort level in completing a psychosocial (HEADSS) assessment with an adolescent.
Q6. Please rate how effective you are at completing a psychosocial (HEADSS) assessment with an adolescent.
Q7. Please rate how comfortable you are at using EBM when motivating patients.
Q8. Please rate how effective you are at using EBM when motivating patients.
Scale: Not comfortable / effective 1 2 3 4 5 6 7 8 9 10 Very comfortable / effective.

the subset of 59 students who had completed both the pre and post questionnaires.

On the pre-intervention questionnaire the median student self-assessed rating was five or below (on the 10 point scale) for six of the eight items. The students rated themselves a six or higher on six of the eight items on the post-intervention questionnaire. Comparing the responses pre and post, after Bonferroni adjustment, items 4, 5, and 8 showed a statistically significant improvement in ratings ($p < 0.05$). These related to effectiveness at managing a confrontational situation involving family members (Q4, $p = 0.01$), comfort at completing a psychosocial assessment with an adolescent (Q5, $p = 0.00003$) and effectiveness using EBM when motivating patients (Q8, $p = 0.0003$). There was a statistically significant decrease in how students rated their comfort using EBM when motivating patients (Q7, $p = 0.003$). While not statistically significant, students rated themselves higher at the end of the week than at the start of the week on the four other questions (**Table 2**). Looking at the change in ratings before and after, for the overall group, the median change was an improvement for six of the eight questions, no change for the question concerning effectiveness at completing a psychosocial assessment with an adolescent (Q6) and a decrease in score for the question concerning comfort at using EBM when motivating patients (Q7). This pattern seems to follow across rotations two, three and four except for two differences: the median change was a decrease for the question concerning comfort communicating with parents and families (Q1) in rotation four; and there was an improvement for the question concerning effectiveness at completing psychosocial assessment with an adolescent (Q6) in both rotation two and rotation four. The results for rotation one appear different from the other rotations, reporting an improvement only on the question concerning comfort at completing a psychosocial assessment with an adolescent (Q5).

Focus Groups

We conducted eight FGDs with a total of 35 students. These were spread across the four included rotation blocks. There were participants from rotation one (12), rotation two (5), rotation three (11) and rotation four (7). Our intention was to capture the experiences of students who participated in each of the rotations which occurred at different times throughout the year. Later rotations would have already completed other clinical rotations in advance of pediatrics. There were male (15) and female participants (20) and participants came from both undergraduate (26) and graduate programmes (9). We identified four main themes that characterized how experiential learning supported and shaped the students' development of pediatric communication skills (**Table 3**).

Theme 1: Shaping Student Learning

Students came into the teaching week looking to gain experience and address preconceived concerns they had about their ability

TABLE 3 | Focus group discussion themes.

Theme	Sub-Themes
Shaping student learning	Drawing on experience Desiring exposure Having concerns
Supporting student learning	Engaging in peer learning Engaging in self-reflection Receiving timely multisource feedback Putting theory into practice Having a supportive environment Having a realistic/authentic environment
Developing new skills	Being a team player Dealing with the unexpected Engaging with children Identifying normal range Interacting with parents Providing age appropriate explanations Learning how to apply knowledge
Feeling more prepared	Getting a good foundation Experiencing graded exposure Changing perspectives Addressing fears Building confidence Developing a pediatric mind-set

in pediatric clinical settings. The students used evocative words to share how they felt about their pediatric rotation, such as:

- *"daunting" S09F, FG1.2*
- *"nervous" S34F, FG4.2*
- *"worried" S29F, FG4.1*
- *"terrified" S06F, FG1.2*
- *"fear" S02M, FG1.1*
- *"scariest thing" S08F, FG1.2*

Students highlighted the abruptness of the transition to clinical practice, describing the process akin to being *"thrown into the deep end" S22M, FG3.2*.

The nature of the students' concerns were quite diverse. Some students were concerned about encountering an acutely unwell child in the hospital and being out of their depth. Other students had concerns about managing difficult situations with parents who were very demanding. Students feared they would not be able capture children's attention to engage well with them.

"I was honestly terrified. I am not really a kid person... I'm kinda glad that we have this week because it's nice to have… almost like a little tutorial..." S06F, FG1.2

Students also brought with them experience from interactions with children outside of their studies through babysitting, sports and family and this experience gave some students confidence.

"... I have a niece and a nephew… I spend a lot of time with them. I find it relatively easy. I enjoy my time with them, communicating with them. I find getting information from them rather easy" S27M, FG3.2

However, even the students who were confident interacting with children in extra-curricular activities were less confident in the medical setting. They desired practice speaking to children about more serious topics and learning how to manage the needs of both parent and child. They acknowledged how there would be additional challenges in situations where a child was very sick or distressed.

"I had prior experience with it because I taught swimming lessons for four years. … and then I was a camp counsellor, … but I imagine communicating with a very sick child who is more distressed will be different." S18F, FG3.1

Theme 2: Supporting Student Learning

Students reported elements within the teaching that helped them learn. Students valued learning from their peers. Some students did not feel comfortable going straight into the simulation so they appreciated the opportunity to watch others first. They also valued seeing how others approached a situation and having the chance to talk through what they found difficult. Watching their peers helped students see the standard to which they should aspire; they appreciated being able to *"model [themselves] after someone who is really good" (S31M, FG4.1)*. Some students would have liked a demonstration from a tutor in advance of the simulation or more time to watch the sample videos as they were not confident about how to approach the consultation. The knowledge that they were being watched motivated students to put in more effort to present themselves well.

"It's good that you have a few of us in the same room as well. It gives you a bit of context and you can like learn from the people before you." S17F, FG2.2

Students appreciated prompt feedback from multiple sources, including personal reflection. They valued how detailed the feedback was from tutors and appreciated receiving it in a timely fashion. They benefited from separating the learning from the doing, describing their difficulty in remembering exactly what they had done afterwards. The video recordings were very useful for them to actually see their actions. Students who had a natural tendency to be critical of themselves identified that the video helped give them reassurance and have a more balanced view of their performance which in turn helped improve their confidence. Even students who described watching their own video as *"cringy" (S04F, FG1.1)* or *"awkward" (S16F, FG2.2)* acknowledged that they learned from it. They indicated how useful it was for identifying subconscious non-verbal behaviors about which they were not aware.

"... I'm always really hard on myself… So having the history recorded… and then watching the video I was like, okay, that actually wasn't that bad... so it's kind of given me a lot more confidence..." S13F, FG2.1

The team-based simulations were not recorded, however, students commented that they would have liked this to be recorded also so they could objectively see their actions during the debrief.

"If the debrief we did afterwards included the video where it's showing you, here you did this, now you did that. That might be good because then you could actually see … Oh yeah, we're so busy." S03M, FG1.1

The structured and supportive environment allowed students to put theory into practice in a safe way. Students valued learning in an environment where they could make mistakes without negatively impacting on patient care or their grades.

"... I think that was the best part because I think you could easily learn then without being like, this is gonna mess up my score or this has so much riding on it. . . " S09F, FG1.2

Students in early rotations requested additional guidance in advance of the SP interaction despite the availability of resources such as videos on an e-learning platform. Students in later rotations reported the opposite, that the level of information provided to them in advance made the interactions too easy.

Students also valued realism. Elements of teaching which improved the realism or authenticity of the situation helped them engage better with the learning. Elements which detracted from realism caused confusion for the students.

"Whereas the simulated neonates that moved and groaned that was incredibly realistic and really helped you feel like you were actually part of a proper team..." S02M, FG1.1

Theme 3: Developing New Skills

Students described how they developed skills, many of which related specifically to communicating in a pediatric environment: engaging children; using age-appropriate language; identifying the normal range and interacting with parents. Students saw the parallels between what they were doing and how they would navigate conversations in the clinical setting. Students spoke about having to be more creative in their conversations with children, teasing information out and trying to judge how much information they could understand. They spoke about learning how to build rapport and engage children through play and visual communication with pictures and drawings. They noted how each child was unique and that different personalities required different approaches.

"... it was good when we were explaining to the children about healthy eating to put it into terms that they can understand...It takes more effort than it does explaining something to an adult..." S04F, FG1.1

"... we were given an opportunity to interact with kids of different age groups...so you kind of have an idea of what to expect with the different age groups. . . " S05F FG1.2

When interacting with SPs students spoke about learning how to adapt their approach to a consultation. They noted differences in approach when talking to an adult patient about themselves compared to a situation where they were talking to a parent about their child. They learned about how parents might feel in such situations and how to reassure them about their concerns. Some students saw the positives, identifying that parents could help them identify problems with their child, acknowledging in adult consultations third parties can only rarely describe how the patient has been.

They developed broader skills such as how to apply knowledge in practice, how to deal with the unexpected and how to be a team player. Students often felt unprepared for the situations they were presented with during the week but despite this feeling, they managed to navigate the situation successfully. Students gained insight into the uncertainty of clinical practice; *"it's not an exact science" (S07M, FG1.2)* and that it was a matter of *"getting comfortable with feeling uncomfortable" (S06F, FG1.2).* They learned about having different roles in a team and how to approach conversations with more senior team members.

". . . when you're going through the phone call [to senior staff], there's this list of things that you're trying to follow, but just start by saying, I'm really worried about this child. I have a very sick child, so we've gotten their attention right away and that's something we're not going to forget now." S03M, FG1.1

Theme 4: Feeling More Prepared

Students felt that they had received a good foundation in pediatrics. Their perspectives of pediatrics changed. The described feeling less anxious about the upcoming clinical placement and feeling more confident in their ability to communicate in a pediatric setting.

"...I think all rotations should have these simulated things in the first week just to ease you in and give you an experience of how it would be like to practice..." S31M, FG4.1

Students also described how they had gained a better understanding of the culture of pediatric medicine and what to expect in clinical practice.

"Even the culture around pediatrics to know before we go into [Hospital], like having interacted with the tutors, now I'm really looking forward to it. Whereas beforehand I was a little bit apprehensive..." S33F, FG4.2

This better understanding changed their perspectives toward clinical placement describing that the *"deep end"* was now *"more shallow" (S19M, FG3.1).* Through experiencing uncertainty yet navigating the experiences successfully helped reassure students that they could also manage challenges on clinical placement. Having had the opportunity to see simulations of an acutely unwell child helped them feel more equipped for the potentially upsetting situations they may encounter in the clinical setting.

Child Health Literacy Assessment

The results of the child health literacy assessment are from the pre-intervention assessment only. Due to the COVID-19 pandemic it was not possible to administer the assessment post-intervention. All questions on the health literacy assessment had the majority of children responding positively (**Figure 2**). The question which had the largest positive response was Question 6 (Finding out which food is healthy for you) (95%), followed by Question 10 (Understand what your parents/guardians tell you about your health) (92%). The question which had the largest negative response was Question 7 (Understanding what your doctor says to you) (27%), followed by Question 2 (Knowing what to do to get well quickly when you have a cold) (26%). The question to which the largest number of children responded "Don't Know" was Question 8 (Understanding why you sometimes need to see a doctor even though you are not ill).

DISCUSSION

We investigated the impact of implementing a novel course that integrated simulation-based learning with interactions with healthy children in advance of clinical placement. We have two main findings: (a) our intervention supported students' learning of pediatric communication skills, and (b) our intervention helped students feel more prepared for their pediatric clinical placement. Our study is one of the first to create an educational intervention to enhance medical students' pediatrics teaching by combining interactions with healthy children outside of the clinical setting with more traditional simulation-based approaches. Similar interventions to support the development of pediatric communication skills in undergraduate medical education involved simulated patient encounters (2, 23) or a community based pediatric health literacy intervention (29), but none of these studies combined the different teaching modalities.

Pediatrics in the Context of Communication Skills Training

Communication skills teaching is integrated into the medical curriculum in RCSI from year one. Throughout the first 3 years students participate in small group tutorials and simulated patient encounters to learn basic history taking skills in a largely systems-based approach according to the Calgary-Cambridge model (30). Students participate in specialty specific communication skills in fourth year during their clinical rotations. The timing of their pediatric rotation would determine which other specialties students had already completed in fourth year prior to their pediatric rotation, however, for most students their pediatric rotation is the first time they spend significant time interacting with children in a clinical setting. While some of the students' concerns about clinical placement are common to all placements, others differ between specialties, with the triadic nature of communication of particular concern in pediatrics (7).

While for other clinical rotations involving adult patients, simulated patients are an established part of teaching communication skills, the challenges concerning the engagement of children as simulated patients requires a different approach in pediatrics. In our intervention we have shown the impact of combining more traditional simulation-based activities, including simulated patients (as parents) and mannequins as patients, which are common place in adult medicine training, with more novel approaches to experiential learning, specific to pediatrics, involving interactions with healthy children outside the clinical setting. Providing opportunities for medical students to interact with healthy children of different age-groups allowed students to become more aware of the development stages of healthy children, develop the skills needed to communicate with different age groups and become more aware of the concerns of parents. While students reported an improvement in their comfort completing a psychosocial (HEADSS) assessment with an adolescent, they did not have the opportunity to interact with adolescents, only the simulated parent of an adolescent. One possible explanation for this improvement is that many of the students would not have known what a HEADSS assessment was at the start of the week since it is unique to pediatrics. Familiarity with the terminology and tool allowed students to feel more comfortable with it. The intervention could be further enhanced by collaborating with a local post-primary school to provide opportunities for direct interactions with adolescents.

Curricular Factors

There were a number of elements in the design of the intervention that students specifically identified as helpful for them. While we studied these in the context of pediatric teaching, they are applicable to experiential learning in other specialties.

The clinical setting can be a stressful environment for learning due to the elevated risks when dealing with sick children. When students already have concerns about their own abilities, this additional concern, can negatively impact on learning at the start of placement (5). In our study, the medical students' concerns about their own ability were evident through both the pre-intervention questionnaire and the FGDs. The students gave themselves low ratings on most of the questions on the pre-intervention questionnaire and during the FGDs the students described distinctly their anxiety toward their clinical placement. In our intervention the safe and supportive learning environment afforded opportunities for students to put theory into practice and make mistakes without any major implications either to the welfare of a child or to their overall grades for pediatrics.

Self-reflection through video-review was a transformative experience for many students. They valued the opportunity to separate their learning from the doing. Due to the high cognitive load of a new situation students spoke about having difficulty remembering the scenario afterwards, describing it as *"erased"* from their mind. Students explained that while immersed in the scenario they were not thinking about how it was going, they were just focusing on what they were doing. Having a recording of themselves to watch afterwards allowed them focus on learning at a separate time from doing the activity itself. With reflective observation a key element of experiential learning theory (12), our findings extend our understanding of how students engage in reflective observation and how technology can support and enhance this process.

Often in clinical settings students are paired with just one other student and are not afforded as many opportunities for group learning. In situations where students were less confident they appreciated the opportunity to watch their peers in action before they participated themselves. They also appreciated watching other students to get different ideas of how to approach a situation. While the traditional understanding of experiential learning focused on reflective observation (12), the learning process as described by the students also aligns with vicarious observational learning (13). Their learning occurred through a combination of these processes described by the two theories. While Johnson (14) suggests that learning in simulation by observation is the same as learning by participation, our study indicates that they differ but influence learning positively. This finding has implications for faculty designing interventions: Both doing and watching provide learning experiences for students, but providing one without the other may leave gaps. By providing doing and observing experiences students can relate their abilities to others and gain a broader understanding of how best to approach a situation.

Students valued timely multi-source feedback. The presence of feedback from multiple sources, tutor, peer, SP and their own reflection allowed them to develop insight into their performance but also understand how their perspective compared to others. Students valued having dedicated time to have discussions with tutors to help figure out different ways to approach situations. Feedback from the SP helped students to understand the importance of empathy and transformed the experience from a tick box exercise to an experience where students learned about how a parent might feel in the situation.

Finally, the structure of the teaching influenced students' perceptions of realism. Elements which added realism to the situation allowed students to engage better with the learning. Students valued how convincing the tutors were in embedded participant roles, how realistic the movements and physical signs were on the neonatal mannequin and how well the simulation environment resembled a clinical setting. Aspects of the scenarios that they found unrealistic presented challenges for them. Students found it distracting that no child was present with the simulated parent during the history taking consultation. Even though they knew they were speaking with a parent they had a natural instinct to interact with the child who was not present.

Preparation for Clinical Placement

Our study confirms previous findings that students can find the transition to clinical placement unpleasant (5). The intervention presented in our study demonstrates how experiential learning prior to clinical placement, can support this transition in pediatrics. The effectiveness of the intervention is evident through the improved student self-reported scores on the pre-post questionnaire and through the insights afforded in the FGDs. In the FGDs students described the various skills, both general and pediatric specific, that they developed which helped them feel more prepared for their clinical placement. They also spoke about gaining greater insight into their own ability, which helped them become more confident. Their increased perceived competence and confidence may help explain why their ratings on the pre-post questionnaire improved for three of the four rotations. For the group in rotation one, the median change in pre post ratings improved for just one question, this question concerned their comfort at completing a psychosocial assessment with an adolescent. Their pediatrics rotation was the first major fourth year clinical rotation for this group so perhaps they could not see how they could translate the learnings outside the clinic into practice. All the other rotations would have seen how, on other clinical placements, they could apply learnings from educational settings to clinical practice. There was one question on the pre-post questionnaire where students reported a decrease in perceived ability. This question concerned their comfort using EBM to motivate patients. In the FGDs, students discussed being worried about managing difficult scenarios with demanding parents or parents who were anti-vaccination. Through the experiences afforded to the students during the week perhaps they gained a greater understanding of the complexity of implementing EBM in practice.

Many students came into their pediatric clerkship with concerns about the challenges that may be presented to them in the pediatric clinical setting. The opportunity to deal with some of these concerns in a safe experiential learning environment in advance of clinical placement helped to alleviate many of the students' concerns. Even students who came to placement with confidence from previous extracurricular experience with children appreciated the opportunity to "ease in" to placement. Having teaching in advance of placement does make the transition less abrupt (4). A lack of knowledge related to specialties contributes to students describing the start of placement as unpleasant (5). Through our intervention students developed skills and a better understanding of the pediatric clinical workplace which helped to alleviate concerns about the transition to clinical placement.

Community Engaged Learning

Our findings highlight the need for further interventions to help children from DEIS schools to understand doctors. The question to which the largest percentage of children responded negatively, on the health literacy questionnaire, related to understanding what their doctor says to them. We could not measure the change in children's perspective after the intervention due to the restrictions on education at the start of the COVID-19 pandemic, but this aspect would be interesting for future study. Exposure to medicine and healthcare workers in training through community engaged learning (21) has the potential to improve children's understanding of topics relating to healthcare. Firsthand experience in talking to children about health related topics gives medical students valuable insights about how to engage with children, how to use understandable age-appropriate language and how to deal with the unexpected.

Limitations

Participation in the pre-post questionnaires and the FGDs was voluntary which means that we may have missed some perspectives. This could mean that the results are biased toward participants who were favorable toward the course as those less favorable may not have volunteered. The low response rate for the post-intervention questionnaire was likely because this was completed in the students' own time after the week was complete. At that point, students' attention had shifted to their imminent clinical placement and the arrangements they needed to make in advance of placement. While the post-intervention questionnaire does include participants from each of the four rotations, the results are only representative of those who responded and a higher response rate may have given us perspectives that were more diverse. A more objective measure of student ability before and after the intervention may have given a clearer understanding of baseline ability and change in ability. While the results of our study show how the intervention changed students' perspectives in advance of their clinical placement, capturing students' perspectives after clinical placement may have given greater insights into whether the intervention truly prepared them for clinical placement in retrospect and is an area for potential future work. The children who participated in the workshops and completed the health literacy assessment were from DEIS schools and their responses would not be representative of the general population. A broader assessment of child health literacy may be beneficial. The impact of the COVID-19 pandemic meant that we had to exclude the fifth rotation of students from the study due to major changes to the teaching. Additional student perspectives, especially those completing pediatrics as their final rotation would have added to the study.

CONCLUSION

Because of their patient-centered nature, pediatric clerkships represent an irreplaceable learning experience. To address the challenges of workplace learning and variations in students' clinical experience, pediatric educators can supplement clerkships with learning in student-focused environments. This can be achieved by combining simulation with interactions with healthy children to allow students to develop communication skills in a safe and structured manner. Key curricular elements which students found supported their learning were: opportunities to put theory into practice; peer learning; timely multi-source feedback and a safe, supportive environment. The use of technology enhanced reflective observation and afforded students additional opportunities for learning after the experience. Medical students who participated in the intervention reported a greater understanding and confidence related to the skills needed for effective communication in pediatric settings. Community engaged learning has the potential to provide a cost neutral and reciprocal method of improving children's understanding of health related topics, whilst also helping future doctors learn how to effectively communicate with children.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

This study, which involved human participants, was reviewed and approved by the RCSI Research Ethics Committee. Written informed consent to participate in this study was provided by the medical students. For the children who participated, written informed consent to participate was provided by the participant's legal guardian/next of kin, as well as written assent from the child.

AUTHOR CONTRIBUTIONS

CS, DOL, and MK contributed to the design of the teaching intervention and research study. CS, DOL, MK, and CC contributed to the ethics submission. CS and MK coordinated participant recruitment. CS, CM, and MK coordinated data collection. CS, MA, CC, and WE contributed to data analysis. CS wrote the manuscript with contributions from MA, DOL, CC, CM, and WE. All authors contributed to manuscript revisions and read and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fped.2022.834825/full#supplementary-material

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METHODS
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Neonatal Simulation Program: A 5 Years Educational Journey From Qatar

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We describe the process of implementation, adaptation, expansion and some related clinical intuitional impacts of the neonatal simulation program since its launch in 2016 in a non-simulation neonatal unit. The team has developed 6 types of curricula: 1 full-day course and 5 half-day workshops. A total of 35 free of charge simulation courses/workshops were conducted, 32 in Qatar and 3 abroad with a total of 799 diverse participants. There was a steady increase in the overall success rate of PICC insertion from 81.7% (309/378) to 97.6% (439/450) across 3 years ($P < 0.0001$). The first attempt PICC insertion success rate has been also increased from 57.7% (218/378) to 66.9% (301/450) across 3 years. The mean duration of PICC insertion has been improved from 39.7 ± 25 to 34.9 ± 12.4 min after implementing the program ($P = 0.33$). The mean duration of the LISA catheter insertion at the beginning of the workshop was 23.5 ± 15.9 compared to 12.1 ± 8.5 s at the end of the workshop ($P = 0.001$). When it came to clinical practise in real patients by the same participants, the overall LISA catheter insertion success rate was 100% and the first attempt success rate was 80.4%. The mean duration of LISA catheter insertion in real patients was 26.9 ± 13.9 s compared to the end of the workshop ($P = 0.001$). The mean duration of the endotracheal intubation at the beginning of the workshop was 12.5 ± 9.2 compared to 4.2 ± 3.8 s at the end of the workshop ($P = 0.001$). In real patients, the first-attempt intubation success rate has been improved from 37/139 (26.6%) in the first year to 141/187 (75.5%) in the second year after the program implementation ($P = 0.001$). The mean duration of successful endotracheal intubation attempts has been improved from 39.1 ± 52.4 to 20.1 ± 9.9 s ($P = 0.78$). As per the participants, the skills learned in the program sessions help in protecting neonates from potential harm and improve the overall neonatal outcome. Implementing a neonatal simulation program is a promising and feasible idea. Our experience can be generalised and replicated in other neonatal care institutions.

Keywords: newborn infant, curriculum development, neonatal simulation program, simulation-based education, healthcare simulation, mastery learning

INTRODUCTION

Numerous factors contribute to neonatal morbidity and mortality, and insufficient experience of neonatal healthcare providers managing crises is one major cause worldwide (1). Neonatal emergency, procedures and resuscitation scenarios are usually complex, challenging, requiring excellent cognitive skills, communication and teamwork between and within the multidisciplinary neonatal healthcare teams handling such cases (2, 3). Practical procedures, neonatal resuscitation skills, critical thinking, communication skills, and effective team dynamics are integral to neonatal care. These domains are essential for the core paediatric speciality and neonatal subspecialty progress curriculum for trainees and established experienced neonatologists (4).

Old-fashioned "trainee" models in medical education do not offer as many opportunities to practise clinical procedures and face hot complex neonatal real-life situations on real patients. Patient safety is a top priority all over the world hence it has resulted in a shift to simulation-based learning (5). Most of the trainees and many mid-career paediatricians join the neonatal speciality with minimal prior exposure to life-saving cognitive and psychomotor skills. Many paediatric residents, unfortunately, finish their education without completing the necessary practical competence and resuscitation expertise in the care of neonates mostly due to non-participation (6, 7). With recent changes in junior and mid-career physician's contracts, reduced working hours and evolving clinical practises, such as favouring less invasive forms of ventilation and surfactant administration worldwide, trainees may not get enough clinical exposure to gain these rare but pivotal skills. As DeMeo et al. further explore, neonatal endotracheal intubation for example remains a critical skill for paediatric residents and neonatal-perinatal fellows in the NICU, but they don't usually get a lot of chances to learn this vital skill (6). Simulation hence remains one of the ways to enhance this vital competency (8, 9).

Simulation-based education is an excellent way of practising problem solving, decision making, understanding human factors, critical thinking skills under pressure, communication reflecting great teamwork and even identifying ergonomics challenges, all of which will ensure better patient care and reduce the risks associated with the daily critical neonatal practise (10). It is considered a safe bridge between theory and practise for this infrequently occurring clinical event. Creating a robust foundation in simulation training, implementing a collaborative, multidisciplinary approach of the healthcare staff, and initiating a quality improvement agenda were important goals leading to the establishment of a Neonatal Simulation Program launched in September 2016 at the Hamad Medical Corporation (HMC).

Abbreviations: WWRC, Women's Wellness and Research Center; IRB, Institutional Review Board; HMC, Hamad Medical Corporation; NICU, Neonatal Intensive Care Unit; LISA, Less Invasive Surfactant Administration; PICC, Peripherally Inserted Central Catheter; CLABSI, Central Line-Associated Blood Stream Infection; ETT, Endotracheal Tube; NRP, Neonatal Resuscitation Program; DHP, Department of Healthcare Professions; MOPH, Ministry of Public Health; CPD, Continuous Professional Development; MRC, Medical Research Center.

PROGRAM OBJECTIVES

The main goal of the Neonatal Simulation Program is to improve patient safety by creating a safe and realistic environment in which all clinical neonatal professionals, be it novice or seasoned, can hone their skills, practise new and advanced techniques, and develop their clinical competencies. This is important, especially for competencies like neonatal intubation, which might be more rarely required in the field, but is a skill of vital importance with no room for errors in the real world. Results from other studies indicate that training models designed for adult practises cannot be readily transferred to neonatal skills without major changes made to the training models (11–15).

By launching the program, we aim to demonstrate, implement and disseminate unique high-quality neonatal simulation-based experiences to participants all over the world. We wanted to encourage enhanced involvement of clinicians, thus making full use of this available training to upgrade their mastery learning and clinical performance. Transferring skills learned in simulation sessions to the bedside might be a challenge. One of the goals of the program is to fill in the gap between the simulation environment and real-life scenarios (16). Another goal of this program was to provide simulation training free of cost, at least at the initial phase, to encourage more participation and increase awareness.

Our objectives align with the HMC's Strategic plan in the establishment of collaboration with partners across medicine. That will be positively reflected in clinical patient care and safety which is our goal.

METHODS

The Women's Wellness and Research Center (WWRC) is the main hospital for women and newborns health services in Qatar. The hospital lies under the umbrella of Hamad Medical Corporation (HMC), Doha, Qatar. WWRC is a tertiary teaching hospital that accommodates more than 18,000 deliveries per year and has a level III NICU with 112 beds. The data were collected retrospectively from WWRC only after getting the Institutional Review Board (IRB) approval from the Medical Research Centre (MRC) in Hamad Medical Corporation (Protocol Number: MRC-01-22-060).

Neonatal practise is an example of crisis resource management where multi-disciplinary teams work together to provide the best possible care for highly vulnerable neonates. It was noted that there is a considerable performance gap in the neonatal team responses, especially in critical situations. As simulation-based education is the best way in learning and enhance team dynamics in such situations, the neonatal simulation team has been launched in September 2016 to enhance the NICU team's performance in critical unusual situations. The neonatal simulation team first designed the neonatal emergencies simulation course in 2016, then the in-situ neonatal simulation workshop in 2017, the neonatal golden hour simulation workshop in 2019, the less invasive surfactant administration simulation workshop in 2020, and the neonatal transportation simulation workshop in 2021.

The neonatal simulation steering committee was formulated from different subspecialties to lead this program. The core team includes two neonatologists, one paediatric nephrologist, two clinical pharmacists, one respiratory therapist, one NICU nurse as well as one nurse educator. Three of the members are internationally accredited in healthcare simulation and medical education. Of those, two hold positions in the Society of Simulation in Healthcare (SSH) and the International Pediatric Simulation Society (IPSS).

After setting the scope, performing the educational needs assessment, and designing the learning objectives, the team has developed 6 types of curricula; 1 full-day course and 5 half-day workshops. Thirty Five free of charge simulation courses/workshops were conducted in Qatar and abroad based upon the educational need's assessment. The full-day course is the neonatal emergencies simulation course which was conducted 8 times; 5 in Qatar and 3 abroad in Egypt, UAE, and Singapore. In addition to that, 27 half-day workshops were conducted in Qatar: 13 *in situ* neonatal simulation workshops, 7 less invasive surfactant administration simulation workshops, 2 neonatal golden hour simulation workshops, 1 neonatal transportation simulation workshop as well as 4 skills lab workshops. The program non-mandatory sessions attracted 799 local, regional and international attendees. We have a total of 46 current facilitators for all the courses/workshops in addition to 4 who already left the program. The team has produced 7 educational videos for different courses and workshops to aid in the educational process. The full-day neonatal emergencies simulation course attracted a total of 337 local, regional and international participants. **Figure 1** shows the number of attendees of the 5 half-day workshops. **Figure 2** indicates the percentages of professions of the participants.

All courses and workshops were approved by the HMC Medical Education Department and were accredited by the Department of Healthcare Professions (DHP) in the Ministry of Public Health (MOPH) with both category I and category III Continuous Professional Development (CPD) hours. The team prepared the required equipment and conducted the first simulation workshops in the Hamad Medical Corporation's Itqan Clinical Simulation and Innovation Center as well as in Sidra Medicine Simulation Center. The logistics of equipment and catering services for the workshops were all supplied by the

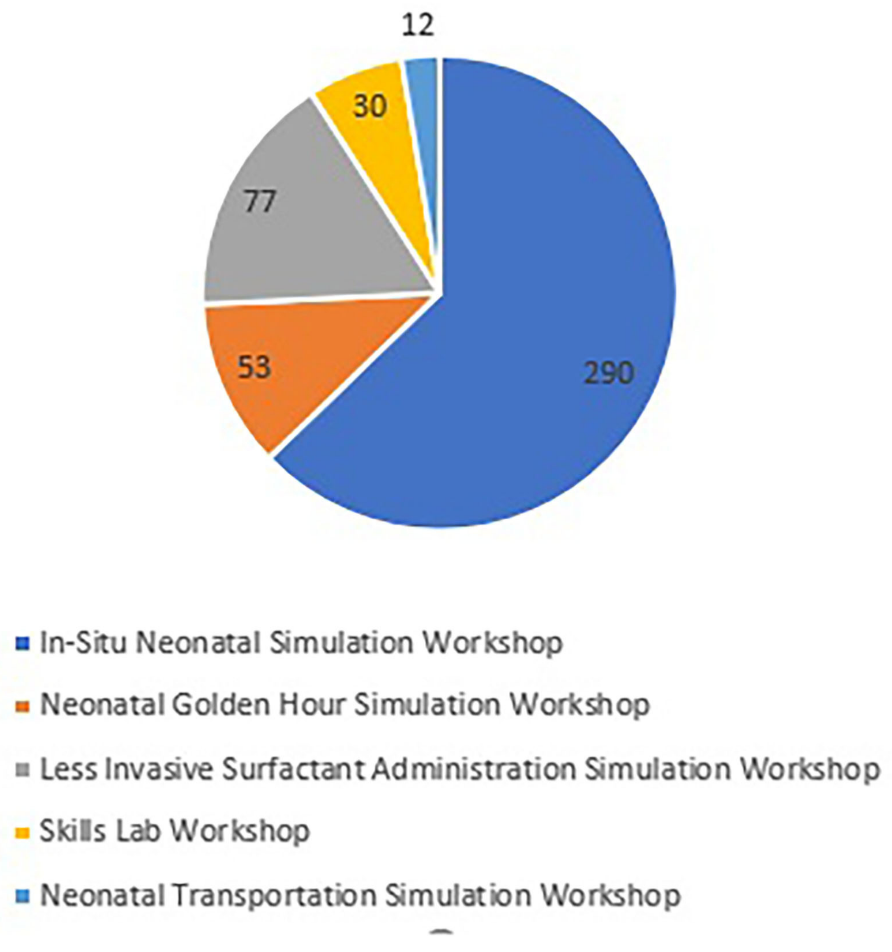

FIGURE 1 | Indicates the number of attendees for the 5 half-day workshops.

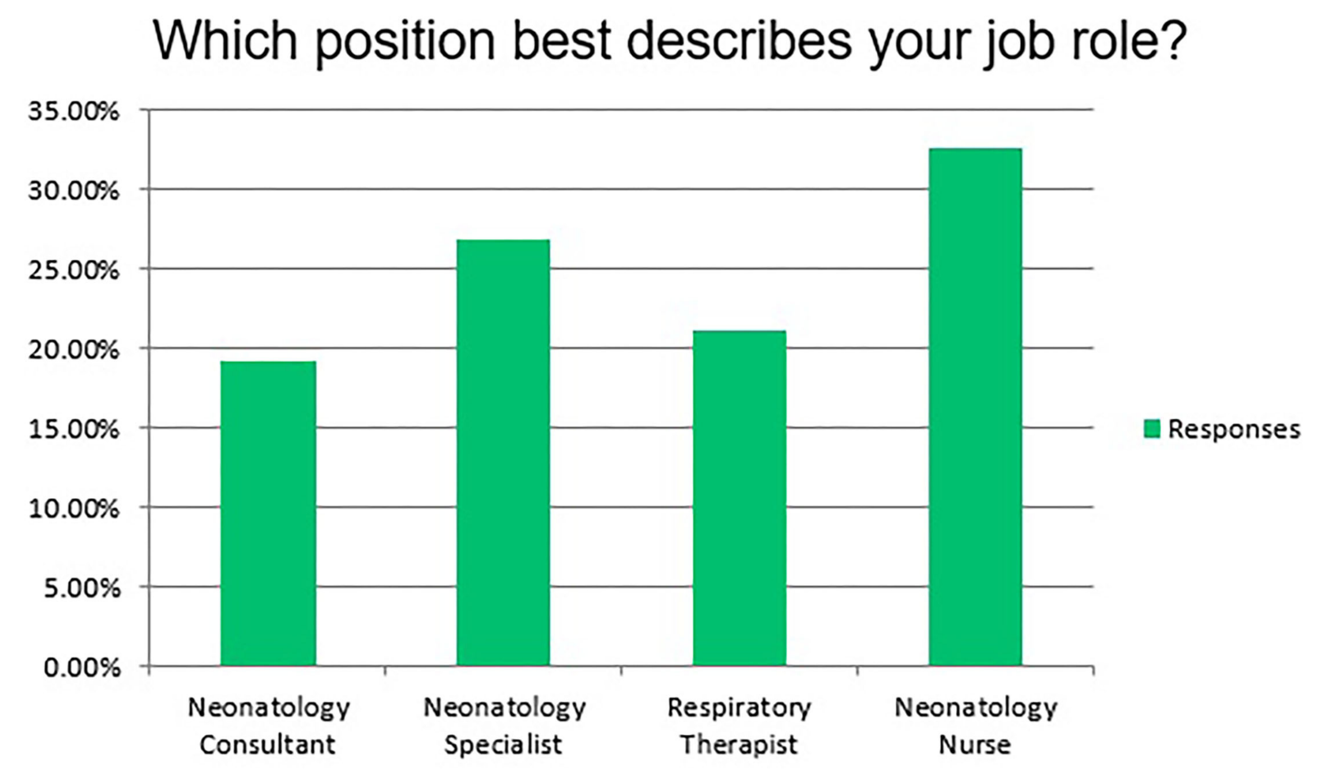

FIGURE 2 | Indicates the categories of the participants.

supporting departments of the Corporation; venues were booked well ahead (6 months to a year) of the planned schedules.

A post-event online survey questionnaire (SurveyMonkey®) was specifically designed for each program curriculum. It was sent to all the participants a few days after the events and it was made mandatory to fill to get the CPD certificate. The survey questions were preliminarily piloted by some learners and facilitators to test the validity, reliability and time needed to fill. The surveys included personal demographic data, venue, facilitator preparation and attitudes, cognitive psychomotor and behavioural skills acquired in the events as well as suggestions and recommendations for improvement.

Neonatal Emergencies Simulation Course

The neonatal emergencies simulation course is a full day course that has 6 complex multi-phasic advanced hands-on neonatal scenarios. In this course, we used high-fidelity manikins (SUPER TORY® S2220, Gaumard). Due to its clinical importance, neonatal endotracheal intubation was practised by the candidates in 3 of the 6 stations. Umbilical venous and arterial catheterization, peripherally inserted central catheterization, chest tube insertion, and lumbar puncture were also practised in different course stations by the participants to promote and maintain their cognitive, psychomotor and behavioural skills at the optimum level. Post-simulation scenario team debriefing was conducted in each station.

Less Invasive Surfactant Administration Simulation Workshop

Due to the current evidence, Less Invasive Surfactant Administration (LISA) has been recently introduced to our day to day clinical practise. Before the implementation, the neonatal simulation team has conducted 7 half-day less invasive surfactant administration simulation workshops. In this workshop, we used the surfactant administration catheter (Surfcath - Vygon Ltd, UK). The accredited workshop has a didactic session, procedural hands-on practise using a medium-fidelity manikin, as well as a debriefing session. The team has ensured that the participant has been skilled enough to practise the procedure in a real clinical situation (17).

Neonatal Golden Hour Simulation Workshop

Extremely low birth weight infants are prone to hypoglycemia, hypotension, and hypothermia after delivery. The neonatal simulation team has developed the neonatal golden hour simulation workshop aiming to reduce the rates of these neonatal morbidities and optimise and standardise the evidence-based clinical care practises during the first hour of life. In this workshop, we used the incubator (Giraffe Incubator Carestation, GE Healthcare, United States) ventilator (Dräger Babylog® VN500), manikin (Premature Anne, Laerdal Medical), and all the other equipment used in the neonatal resuscitation program course. This workshop has a didactic session with video materials, a complex timed preterm inter-professional resuscitation scenario using a medium-fidelity manikin, followed by a post-resuscitation team debriefing (18, 19).

Skills Lab Workshop

Rare neonatal procedures might be very challenging even for experienced neonatologists. This might be due to its difficulty and being very rare to face in real life. To obtain and maintain the staff privileges for these procedures, the NICU deputy director has designed this half-day workshop to practise the exchange transfusion, peripheral arterial line insertion, abdominal paracentesis, intraosseous needle insertion, and pericardiocentesis (20, 21).

Neonatal Transportation Simulation Workshop

The neonatal transportation program in HMC is considered the first retrieval program in the region with more than 1,100 local, regional and international transports. Safe local, regional and international neonatal transportation requires a highly reliable and efficient inter-professional transportation team that is expert enough to provide advanced neonatal care in unusual and resource-limited situations. Providing didactic and experiential learning alone has been proved to be insufficient to fully prepare the interprofessional neonatal transportation teams that have limited exposure to rare unexpected events. Simulation-based education has been proved to enhance and maintain knowledge, skills, and the experiences of different interprofessional transportation team members (5, 22). The workshop has a video-assisted didactic part, 4 hands-on sessions using medium and high fidelity manikins and finally a debriefing session (5).

In-situ Neonatal Simulation Workshop

In-situ neonatal simulation workshop has been conducted by the team in the NICU many times. The content and the scenario varied each time based upon the educational needs assessment and staff requests. This included communication skills scenarios, conflict resolutions, resuscitation skills monitoring, debriefing skills, procedural skills, team responses and inter-professional team development (4, 23, 24).

Statistical Tool

Descriptive statistics in the form of mean and standard deviations for interval variables and frequency with percentages for categorical variables were calculated. Chi-square tests were applied to see the association between the two categorical variables. Unpaired Student *t*-tests or Mann Whitney U tests as appropriate were applied to compare interval variables between the two categories. Paired student t-tests were applied to see a significant difference in mean durations of LISA catheter insertion at the beginning versus the end of the LISA simulation workshop and between the end of the workshop and the duration in real patients. Additionally, the paired student t-tests have been used to see a significant difference in the mean duration of endotracheal intubation at the beginning versus the end of the neonatal intubation simulation workshop. *P*-value 0.05(two-tailed) was considered a statistically significant level. SPSS 28.0 statistical package was applied for statistical analysis.

RESULTS

The courses and workshop gradually increased in number and quality based upon the participant's requests as well as the needs assessment.

Simulation-based education has since become a routine part of the unit's educational activity over the last years (**Figure 1**). Overall, the program has been well received by the participants. The data obtained from the post-event survey each session was analysed. Overwhelmingly positive feedback was received with suggestions for improvement and some requests. Candidates derived generic learning points and participants' self-reported data from surveys include improved targeted communication skills, clear leadership roles, role clarity, confidence, teamwork, knowledge sharing within the team, raising concerns, constructive intervention, and regular reflection and re-evaluation. In the post-event surveys, the participants commented that the program has helped enrich their technical, emotional and critical thinking skills, which they believe will help them to transfer those skills in a real clinical environment. These frequent courses/workshops gave the candidates the full chance to practise more and to master their technical, cognitive, and psychomotor skills (25, 26). Each course/workshop has been repeated many times as per the educational needs assessment and participants' requests. Conducting the program sessions, facing unexpected situations, timely preparation, and using the participants' and facilitators' feedback has improved the session's quality over time and decreased the undesired events.

PROGRAM IMPACTS ON CLINICAL PRACTISE

Simulation is considered as the safe bridge between theory and clinical practise. The aim of neonatal simulation-based education is not only to learn and maintain new skills but also to enhance and ensure the soft transferability of these skills from simulation to clinical practise. The success of any simulation program depends on its ability to bridge the gap between simulation and clinical practise (26, 27). We are reporting some clinical impacts of the program on neonatal clinical practise. More detailed clinical outcomes for each course/workshop are beyond the scope of this article.

We traced the overall and first-attempt success rate of the Peripherally Inserted Central Catheters (PICCs) in the first 3 years after conducting the central line simulation workshops. **Figure 3** shows the gradual sustained improvement in both overall and first-attempt success rates across the 3 years.

The mean duration of PICC insertion has also been improved from 39.7 ± 25 to 34.9 ± 12.4 min after implementing the central line simulation workshops ($P = 0.33$). This duration was measured from the start of the procedure scrubbing till removing

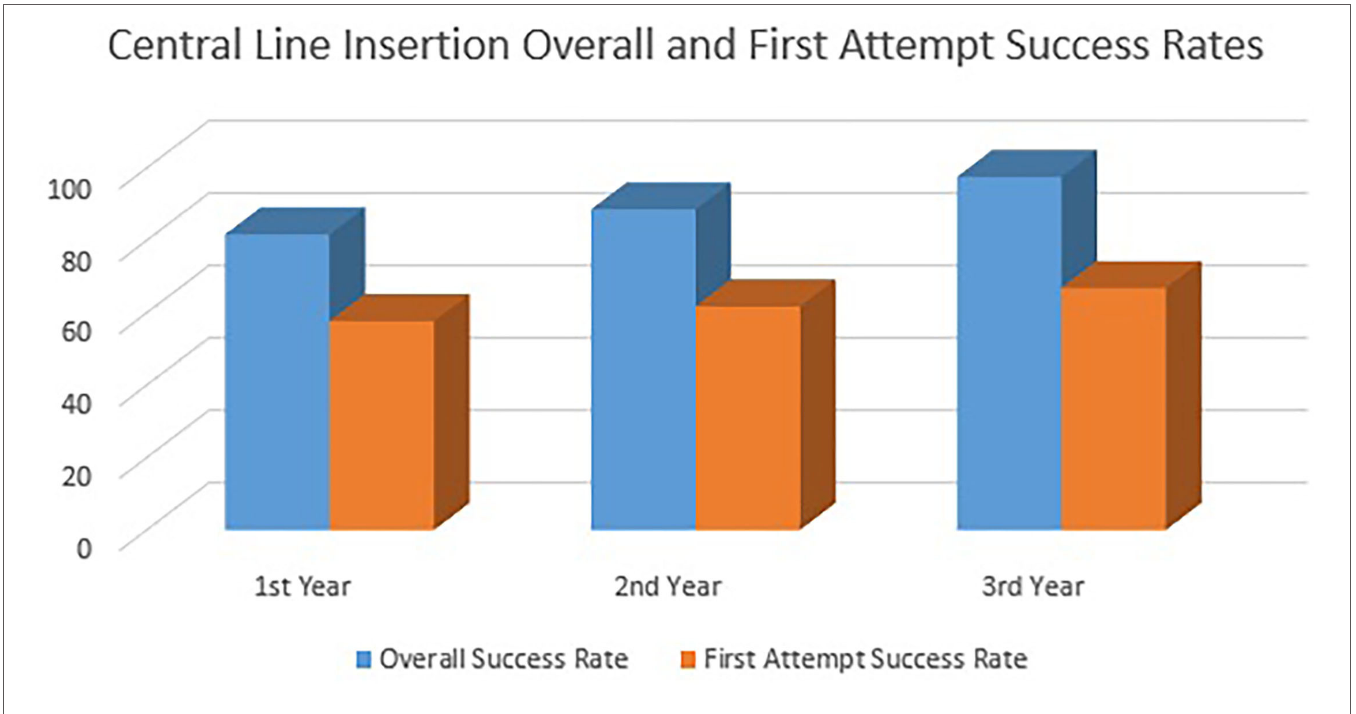

FIGURE 3 | Indicates the central line insertion overall and first attempt success rates.

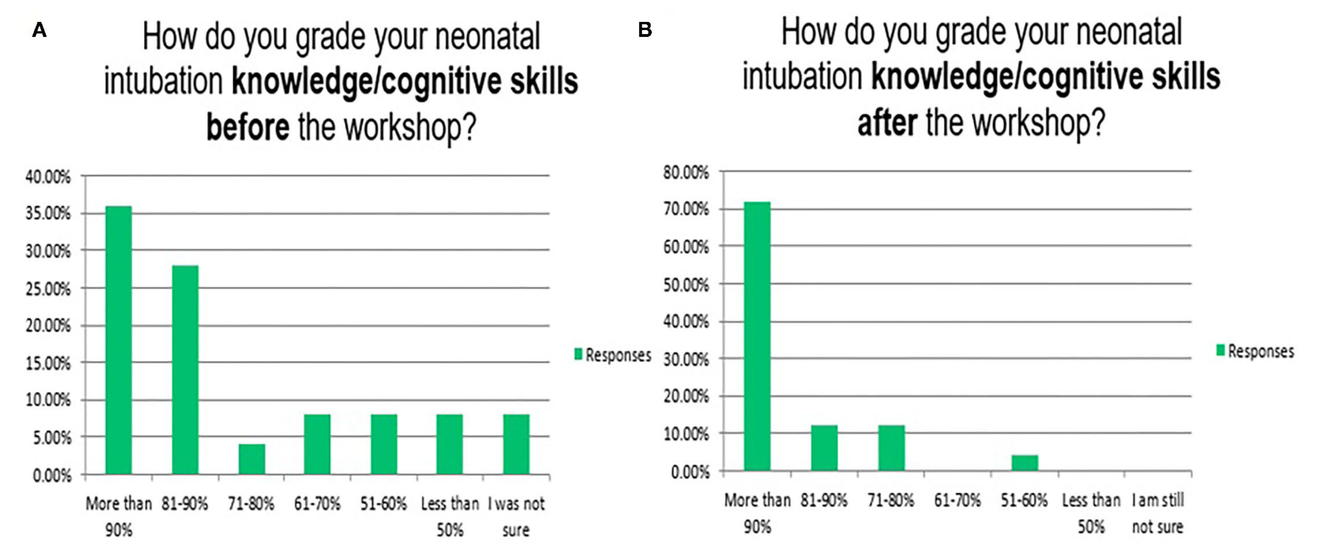

FIGURE 4 | Reflects the attendees' perception/opinion of their knowledge/cognitive skills of the neonatal endotracheal intubation before **(A)** and after **(B)** the simulation event.

the personal protective equipment. A duration of 24.1 min is reported in the literature (28).

Another highlighting impact of our program is the Less Invasive Surfactant Administration (LISA) which has been introduced to our neonatal practise in 2020. The team has conducted 7 simulation workshops for the healthcare providers involved in this procedure. LISA Catheter insertion is a critical skill that might be challenging for learners to acquire and master within the time frame of 30 s even for those who attended the simulation workshop. One of the workshop aims was to let the participants practise the procedure as much as possible to get their confidence to do it in real patients using the rapid cycle deliberate practise (29, 30). The mean duration of the LISA catheter insertion by the participants at the beginning of

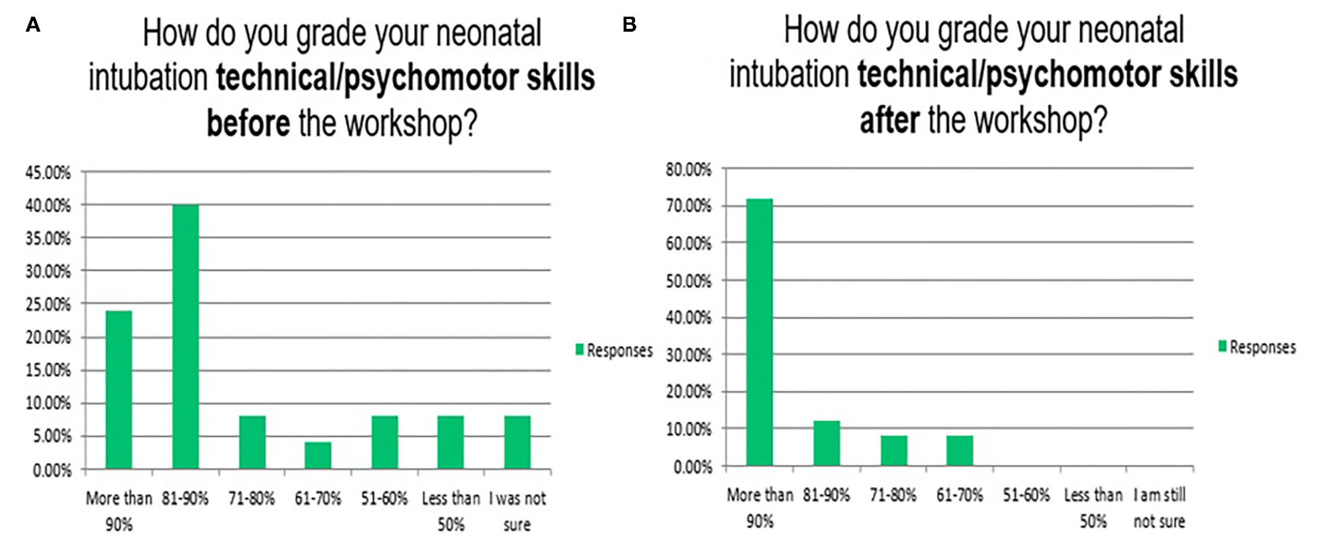

FIGURE 5 | Reflects the attendees' perception/opinion of their technical/psychomotor skills of the neonatal endotracheal intubation before **(A)** and after **(B)** the simulation event.

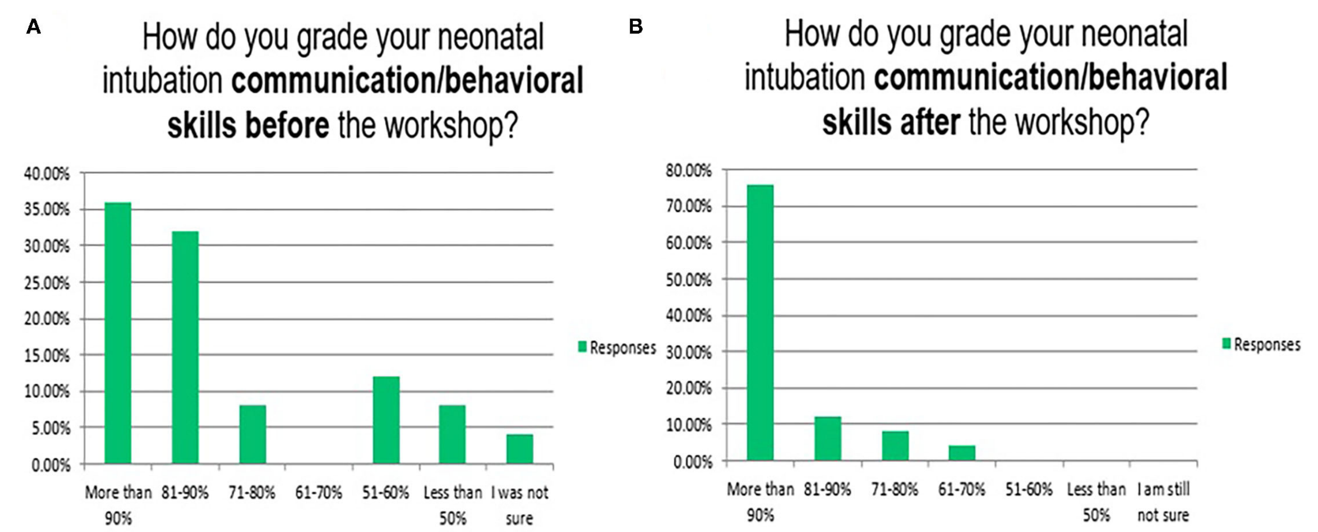

FIGURE 6 | Reflects the attendees' perception/opinion of their communication/behavioural skills of the neonatal endotracheal intubation before **(A)** and after **(B)** the simulation event.

the workshop was 23.5 ± 15.9 s and the end was 12.1±8.5 s after completing the rapid cycle deliberate practise ($P = 0.001$). When it came to clinical practise in real patients by the same participants, the overall LISA catheter insertion success rate was 100% and the first attempt success rate was 80.4%. The mean duration of LISA catheter insertion in real patients was 26.9 ± 13.9 s compared to the end of the workshop ($P = 0.001$).

Neonatal endotracheal intubation is a crucial procedure (31). In our program, the knowledge/cognitive, technical/psychomotor, and communication/behavioural skills for neonatal endotracheal intubation have been taught in 3 of the 6 complex interprofessional simulation scenarios/stations of the neonatal emergencies simulation course as well as in the *in-situ* neonatal simulation workshop (32). **Figures 4–8** reflect the attendees' perception/opinion of their 3 learning domains of the neonatal endotracheal intubation before and after the simulation event.

The mean duration of the endotracheal intubation by the participants at the beginning of the workshop (12.5 ± 9.2 s) and the end (4.2 ± 3.8 s) after completing the rapid cycle deliberate practise ($P = 0.001$). In real patients, the first-attempt intubation success rate has also been improved from 37/139 (26.6%) in the first year to 141/187 (75.5%) in the second year after the program implementation ($P = 0.001$). The mean duration of

FIGURE 7 | High-fidelity manikin and incubator used in neonatal simulation program events.

FIGURE 8 | Itqan clinical simulation and innovation centre in hamad medical corporation.

successful endotracheal intubation attempts has been improved from 39.1 ± 52.4 to 20.1 ± 9.9 s ($P = 0.78$). Other institutions reported 49, 50, 60, and 64% as first attempts success rates. It is highly operator dependent (8, 22, 33). It is important to mention that most of our tracheal intubations are performed by neonatal-perinatal fellows and advanced neonatal providers e.g., specialists and consultants rather than the trainee paediatric residents. This explains the gradual decrease in opportunities for trainee paediatric residents to perform tracheal intubation in their neonatology rotations (19).

The Neonatal Resuscitation Program (NRP) recommendation for laryngoscopy and intubation duration is <30 s starting from the introduction of the laryngoscope (30). However, there is a difference in the procedural time between the simulation at the end of the workshop and the clinical practise in both LISA catheter and ETT insertions. This procedural time difference might be explained by the slipperiness, secretions, and softer textures of babies compared to the mannequins. Moreover, the interprofessional nature and stressors of the NICU clinical environment play a role in creating this procedural time difference (33). One of our program goals is to narrow the performance gap between simulation and practise.

DISCUSSION

This program is the first of its nature in Qatar. The growing population in the country and region creates a need for the establishment of more neonatal simulation programs.

This program was created to improve quality, patient safety and provide the safest, most effective and compassionate care. These were effectively demonstrated by:

- Development of clinical situational approaches based on quality and patient safety improvement.
- Enhancement of multi-disciplinary teamwork.
- Demonstration and proof of improvement.

The key features of the success of program implementation were staff dedication, hard work, persistence, sacrifices, and discipline. The team has volunteered their time, money and effort to get successful. We faced many rejections, criticism, doubts, failures, complaints and we were able to overcome them. This can be attributed to careful planning with systematic execution, positive thinking, continuous professional development, collaborating available experience, administrative support, and extensive regular training of the staff before, during and after activation. Inter-Professional Education allowed the instructors and the participants to learn with, from, and about each other.

Our results show a sustained improvement in different neonatal procedural skills including PICC insertion, LISA, and endotracheal intubation overall and first-attempt success rates. By the end of our program sessions, the times needed to perform the procedures have been significantly shortened. However, there is still a gap between the simulation and clinical scenarios in real patients and retention of the acquired skills in simulation sessions remains a challenge. Despite the ongoing effort of enhancing the realism, psychological, physical, conceptual and environmental fidelity, the appearance, texture, and function of the manikins are still different enough from the real patients. This might be contributed to the confounders and stressors usually present in the clinical environment leading to a performance gap between the simulation and real patients (33, 34).

One of the biggest challenges was attracting interested attendees due to the lack of simulation culture in Qatar at that time. Not all staff believed in simulation as a great tool for adult learning and practical experience and some said it is just an act! With continuous efforts to raise awareness about the importance of simulation-based education, our average attendance rose to 30 per workshop. The lowest number of attendees per event was 2 and the highest was 95.

Logistics was another challenge due to the varying numbers of attendees as well as the many training sessions planned. Although all arrangements and booking of required resources including auditoriums, were done months in advance, the organisers had to change plans to best fit the circumstances of the training day. For example, larger workshops of 95 attendees could not be accommodated in smaller training rooms as originally planned. Instead, the training was shifted to a large auditorium. Unfortunately, this also meant that not all participants could have a chance to practise certain procedures. To overcome this, a camera connected to the live screen was installed before the session and all the participants observed the scenario and procedure steps in detail on the screen. Different combinations of available rooms were tried during the different training sessions to provide the best learning environment for the attendees.

The lack of trained, fully dedicated facilitators was yet another challenge. Preparation for a full day simulation workshop is time-consuming, effort-intensive, expensive and stressful especially if there is no financial benefit for such volunteers and their simulation work is not recognised as part of their core work responsibilities.

Preserving session times and calendar bookings for facilitators and participants from different neonatal specialities was also a challenge in the busy NICU environment. Many of the supporting staff could not continue supporting the program due to clinical commitments, time constraints, and lack of financial benefits! To overcome this challenge, we tried to choose those who were fully dedicated to the pursuit of education and patient safety. However, this remains a big challenge!

The availability of the task trainers for some complex neonatal procedures was another challenge especially abroad. Examples include peripheral vascular access mannequin, lumbar puncture, umbilical catheterization and the chest tube task trainers. The mannequins and task trainers are expensive. As the need is the mother of invention, we created our task trainers for certain neonatal procedures. The task trainers include chest tube trainers, lumbar puncture task trainers, peripheral vascular access as well as the umbilical vascular access task trainer, made with lower technology but are with high fidelity.

Funding is the biggest challenge, and this is especially true when sessions are conducted outside of Qatar. The corporate has thankfully provided the venue, equipment, and caterings for the courses/workshops in Qatar. The additional cost for the courses/workshops conducted in Qatar only is QAR 31900 during the 5 years and that was all shouldered by the core team. It included courses filming and editing, camera and its accessories, stands, posters, special mannequin's maintenance and spare parts, online survey subscription, bells and stopwatches, and gifts for the best participants. For the 8 events conducted abroad, the cost included the flights' bookings, hotel's bookings, visas fee, and conferences registrations whenever applicable for 2-3 facilitators in each of the 8 events and that was also shouldered by the core team. We did not receive any support from the corporate or any of the simulation or pharmaceutical companies in the 5 years. Program sponsorships will enable the team to achieve more in the field of simulation-based education.

LIMITATIONS AND FUTURE DIRECTIONS

The main limitation is the retrospective nature of the study and the self-reported data from the participant's surveys.

Future goals of this program include:

- Designing validated assessment tools to help acquisition and assessment of different cognitive, psychomotor and behavioural skills.
- Establishing the frequency of simulation-based training/re-training to enhance and maintain the knowledge and skills for participants of different clinical expertise.
- Narrowing the gap between the performance in simulation and actual clinical performance.
- Increased use of simulation of various congenital abnormalities and enhancing its realism by the use of moulage.
- More tailoring of different complex non-resuscitation scenarios to mimic medical issues in the NICU as realistically as possible.
- Increased use of high-fidelity simulation is known to have a positive effect on learning.
- Expanding simulation beyond technical skill acquisition, conducting simulation research in human and system performance, ergonomics, and incorporating simulation into high-stakes skill assessments including leadership, risk and resources management are ongoing and pending tasks to complete our mission (35, 36).

We received invitations to conduct and replicate our simulation courses/workshops in Sudan, Egypt, Pakistan, Uganda, Rwanda, and Cambodia. Lifting the COVID-19 restrictions and program support will enable the team to move freely and conduct more sessions around the world.

The program will remain as the team believes that education is a continuous journey, not a destination, with much more to contribute to learning. We aim to expand by developing new curricula and by increasing the number of sessions of the already existing courses/workshops.

CONCLUSIONS

Implementing a neonatal simulation program is a promising and feasible idea. Our experience can be generalised and replicated in other neonatal care institutions. The program provides support, resources, knowledge and encouragement. From our perspective, it facilitates reaching a considerable level of achievement within the main three pillars of health services; health, education and research.

There are ample research opportunities in neonatal simulation including research on different aspects of patient risk reduction, medical education, human factors, ergonomics, behavioural skills, patient safety, personnel training, communication within & between teams, as well as the universal application of new treatment practises and/or procedures. We hope to incorporate all these factors into future neonatal simulation research activities.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

Written informed consent was obtained from the individuals for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

MB and EE contributed equally as co-first authors. They conceptualized, designed and founded the program, got the approvals and accreditations, did the educational needs assessment, designed the learning objectives, developed the program curricula, designed the scenarios, surveys and data collection instruments, coordinated and supervised data collection, paid the cost for all the program courses/workshops, drafted the initial manuscript, and reviewed and revised the manuscript. ME and SL contributed equally as co-senior last authors. They approved and supported the program, designed the neonatal emergencies simulation course, and the skills lab workshop respectively, designed data collection instruments, and critically reviewed the manuscript for important intellectual content. HA designed the neonatal emergencies simulation course and data collection instruments and reviewed the manuscript. MR, SD'S, JF, and AR helped in program logistics and equipment, collected data, and reviewed and revised the manuscript. OK conceptualized and designed the neonatal golden hour simulation workshop, and reviewed and revised the manuscript. JA conceptualized and designed the less invasive surfactant administration simulation workshop, and reviewed the manuscript. AG conceptualized, reviewed and supported the less invasive surfactant administration in the NICU and designed the data collection sheet for an *in-situ* neonatal simulation workshop. FA conceptualized and designed the neonatal transportation simulation workshop, and reviewed the manuscript. RS performed the statistical analysis. All authors approved the final manuscript and agree to be accountable for all aspects of the work.

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Improving Pediatric/Neonatology Residents' Newborn Resuscitation Skills With a Digital Serious Game: DIANA

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Background: Serious games, and especially digital game based learning (DGBL) methodologies, have the potential to strengthen classic learning methodology in all medical procedures characterized by a flowchart (e.g., neonatal resuscitation algorithm). However, few studies have compared short- and long-term knowledge retention in DGBL methodologies with a control group undergoing specialist training led by experienced operators. In particular, resident doctors' learning still has limited representation in simulation-based education literature.

Objective: A serious computer game DIANA (**DI**gital **A**pplication in **N**ewborn **A**ssessment) was developed, according to newborn resuscitation algorithm, to train pediatric/neonatology residents in neonatal resuscitation algorithm knowledge and implementation (from procedure knowledge to ventilation/chest compressions rate). We analyzed user learning curves after each session and compared knowledge retention against a classic theoretical teaching session.

Methods: Pediatric/neonatology residents of the Azienda Ospedaliera Universitaria Pisana (AOUP) were invited to take part in the study and were split into a game group or a control group; both groups were homogeneous in terms of previous training and baseline scores. The control group attended a classic 80 min teaching session with a neonatal trainer, while game group participants played four 20 min sessions over four different days. Three written tests (pre/immediately post-training and at 28 days) were used to evaluate and compare the two groups' performances.

Results: Forty-eight pediatric/neonatology residents participated in the study. While classic training by a neonatal trainer demonstrated an excellent effectiveness in short/long-term knowledge retention, DGBL methodology proved to be equivalent or better. Furthermore, after each game session, DGBL score improved for both procedure knowledge and ventilation/chest compressions rate.

Conclusions: In this study, DGBL was as effective as classic specialist training for neonatal resuscitation in terms of both algorithm memorization and knowledge retention. User appreciation for the methodology and ease of administration, including remotely, support the use of DGBL methodologies for pediatric/neonatology residents education.

Keywords: DGBL, digital games, technology-enhanced training or learning, neonatal resuscitation, memory and retention, newborn infants, healthcare education, serious game

INTRODUCTION

Globally, an estimated 2.5 million newborns die each year worldwide from childbirth asphyxia (defined as a failure to initiate or sustain spontaneous breathing at birth) (1) as ∼15% of full term births require effective resuscitation (2). Correctly performed neonatal resuscitation can save around 700,000 lives worldwide every year (SIN [Società Italiana di Neonatologia, Italian Neonatology Society] Survey on the organization of care in the delivery room, 2020). However, resuscitation guidelines are not adhered in more than 90% of cases (3).

Digital game based learning (DGBL) methodologies have proved effective in multiple medical contexts (4–6) by integrating the advantages of the classic teaching process with the possibilities offered by the use of simulations (replicability, standardized teaching environment, user adaptability of the procedure). They can be applied to most flowchart-based medical procedures and, crucially, their high repeatability and the possibility of dividing each session into several parts can stimulate procedural memory (7, 8). Further advantages of DGBL methodologies include the provision of an optimal context for user result analysis (every action performed by the learner is stored) and a higher attention/appreciation rate by users.

While it is questioned whether DGBL approach can fully replace classic teaching methodologies (9–12), DGBL methods are known to be effective in checking what was learned and reinforcing motivation to enhance adult learning in medical education (13) and, more in general, in higher education (14). With particular regard to medical practice (14–16), and especially neonatal resuscitation (9, 17, 18), numerous existing studies demonstrate the effectiveness of DGBL/simulation methods in stimulating better learning. However, many of these studies lack a scoring baseline (pre-test), a subsequent follow up to evaluate knowledge retention, and/or a homogeneous and independent control group.

DGBL methodologies can be applied to most flowchart-based medical procedures. In this study, we implemented a new ad hoc digital serious game **DIANA** (**DI**gital **A**pplication in **N**ewborn **A**ssessment) and we developed it for neonatal resuscitation teaching. Rather than focusing on a single skill (e.g., endotracheal intubation) this computer game aims to teach the entire neonatal resuscitation algorithm. Unlike most published studies, which involved medical students (9, 19, 20) and expert neonatal professionals (17, 21) as learners, we tested it on a group of resident students of varying experience, using a randomized control study design with the primary goal of testing short- and medium-/long-term knowledge retention [primary endpoint: compare knowledge retention of DGBL and classical training]. The analysis is done by comparing the DGBL group with an independent group undergoing classic training (e.g., 80 min theoretical teaching session provided by an expert neonatal trainer). Indeed, despite an autonomous training using didactic material (9), the choice of a guided approach provides a more controlled training path (10). In addition, several other secondary endpoints were tested to evaluate the performance obtain from DGBL recording scores: knowledge scores, time decision, ventilation/chest compression rate, and user acceptance of this new training methodology.

MATERIALS AND METHODS

Software Description

The DIANA software was developed according to newborn resuscitation flowchart to verify DGBL methodology for training. The DIANA software code was implemented with the real-time development platform Unity (https://unity.com/). The video game was divided into four sessions (i.e., distributed study) with an inter-study interval (ISI) of 48 h to consolidate information memory through repetition (4). Each game session consisted of a theoretical and an interactive part. The interactive part started with 1 min of equipment check. The interactive part simulated a clinical case, where the user would choose how to proceed from one of four options provided. A virtual assistant would intervene in case of errors, and provide detailed instructions to enhance learning without diminishing the gaming experience (22). In the theoretical part, the same virtual assistant, with a human voice, would give a theoretical tutorial using videos to demonstrate technical skills. The first session included an interactive game and complete theoretical teaching about the whole neonatal resuscitation procedure. In the second session, the theoretical part addressed equipment check, neonatal care, and assisted ventilation. The interactive part of the video game followed on from the first session, with successful resuscitation after correctly assisted ventilation. In the third session, the theoretical part dealt with endotracheal intubation skills, chest compressions, and drug delivery, with the interactive part of the video game ending after the execution of chest compressions. Lastly, the fourth session consisted of three activities: a tutorial on venous umbilical catheter insertion, a mini game related to the procedure, and the full execution of resuscitation simulation as in the first session (**Figure 1**). To the aim of the present study, residents did not have free access to the software except for sessions scheduled on the basis of the time intervals described in the study.

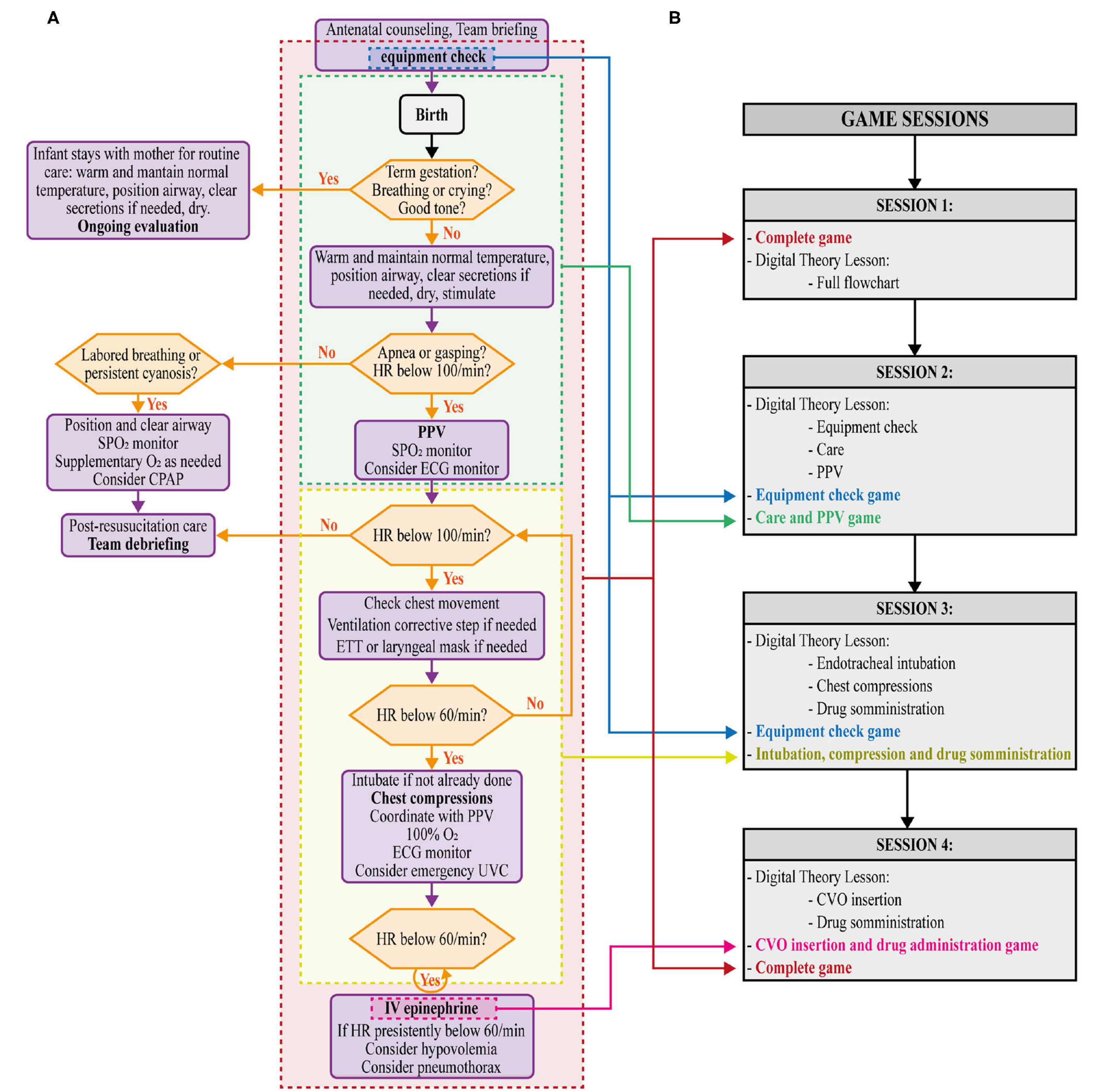

FIGURE 1 | (A) Newborn resuscitation flow chart showing corresponding sections in the DIgital Application in Newborn Assessment (DIANA) game (equipment check, neonatal care and PPV, intubation, chest compression and drug administration, umbilical vein catheterization [UVC, CVO in Italian and consequently in this game version] and drug administration, and complete). **(B)** Details of the game sessions (1,2,3,4).

In this work, we scheduled the DIANA sessions to ensure the same time practice between residents. However, for future practical uses of DIANA to support classical training, this fixed schedule is not imposed by the software. Indeed, DIANA does not impose on the user the sequential use of the game levels (e.g., a practitioner can freely select one of the four sessions). This allows the end user to freely practice on a single flowchart topic or to assess their knowledge of the entire algorithm. The only limitation is that the user within the session will be guided to follow the theoretical part first and then the practical part.

Within the interactive video game, the user had 1 min to select the essential tools (**Figure 2A**), categorized as totally correct, partially correct, and incorrect. Depending on the tool, size and setting selection would be required. After 1 min, the chosen

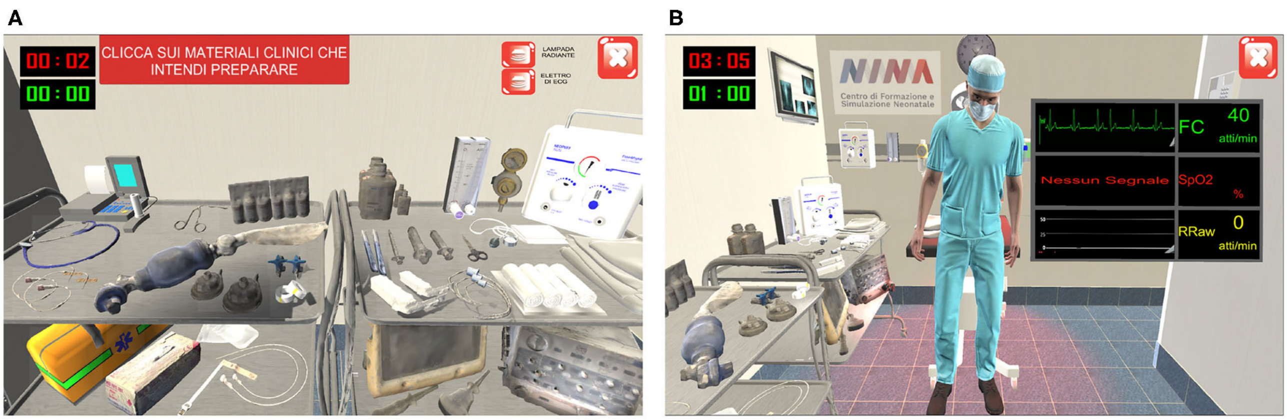

FIGURE 2 | Software screenshots: Equipment check **(A)** and dynamic curves of the simulated newborn's main vital signs **(B)**. In equipment check **(A)**, the user follow the instruction of the game in the red box in the left corner (in English: "click on the materials you want to check").

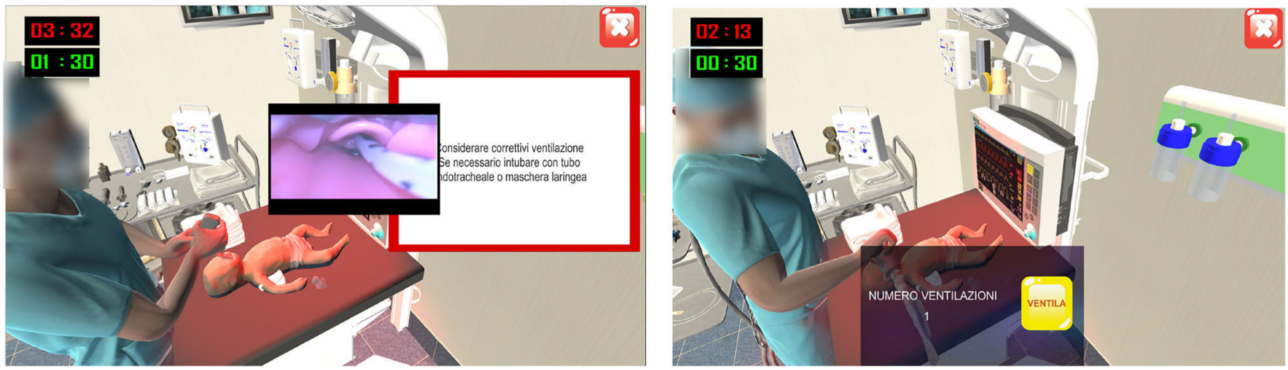

FIGURE 3 | Software screenshots: Execution of endotracheal intubation and assisted ventilations by the virtual assistant. During the execution by virtual assistant, the user gets some useful advice as seen in the white panel: "consider corrective actions for ventilation, such as endotracheal intubation or laryngeal mask insertion." During the execution of assisted ventilation, the virtual assistant squeezes the Ambu bag when the users click on button VENTILA ("ventilate"). The number of ventilation acts performed is showed next to VENTILA button.

tools would appear in a box, checked in green ("selection made") or red ("missing" equipment). When assessing the clinical state of the patient, a monitor would show dynamic curves and heart rate, respiratory rate, and oxygen saturation (**Figure 2B**). Practical procedures were performed by the virtual assistant (**Figure 3**). During ventilation execution, the user defined the timing of the ventilation by selecting a "Ventilation" button. The game was designed to last 30 s, during which, every 10 s, the assistant's voice would reassuringly provide feedback to the user, e.g., advising them to increase or reduce the rhythm or complimenting him/her for maintaining an optimal respiratory rate in assisted ventilation. Importantly, chest compressions execution would imply cooperation between user and virtual assistant: the former would perform the required three chest compressions, following one assisted breath by the latter.

Study Design and Procedure

Study participants filled a questionnaire to assess their previous knowledge and experience (**Figure 4**). Based on questionnaire results, two homogeneous groups [Stratified random sampling, similar to other DGBL studies, (12, 23)] were randomized to either the classic teaching process (frontal teaching session) or the one based on digital simulations (DGBL), respectively.

The theoretical teaching session (**Figure 4**, in purple) was given in person by an expert neonatal trainer, with no more than 10 medical residents for each group, which allowed them to take a very interactive lesson. After finishing the theoretical part, residents practiced the technical skills of PPV, chest compression, and endotracheal intubation on a medium fidelity mannequin (Newborn ANNE, https://laerdal.com/it/doc/222/Newborn-Anne). Neither in the theory lesson nor in the software a specific (limited) clinical case was presented and discussed. On the contrary, in both training residents were asked to perform the whole resuscitation algorithm.

The DGBL group training methodology is based on the use of DIANA software. The software guided the user through the entire resuscitation flowchart divided into four phases. Indeed, starting

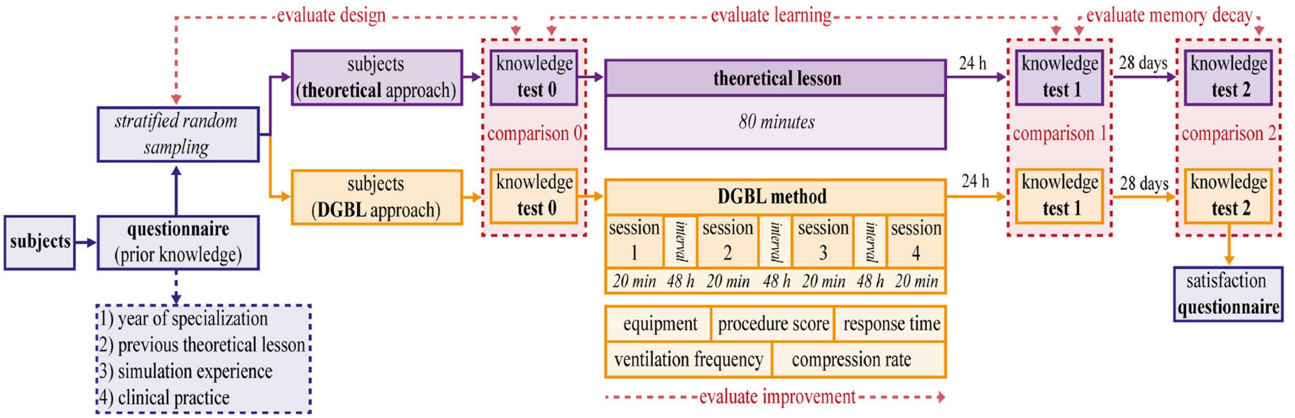

FIGURE 4 | Study analysis scheme. Subjects are divided using a stratified random sampling into two homogeneous and independent groups, based on the score in a prior knowledge questionnaire. The first group (theoretical lesson) is trained by an expert neonatal trainer for 80 min. The second group (digital game based learning [DGBL] method) is trained using DIgital Application in Newborn Assessment (DIANA) for the same length of time on four different sessions. Three written tests (0 pre-test, 1 post-test, 2 follow-up) are used to compare the methodologies (comparisons 0, 1, 2) and to evaluate learning and memory decay. The knowledge test 0 is used to evaluate the stratified random sampling.

from the promising results obtained even with a single session of a serious game approach (9, 17, 21), DGBL group (**Figure 4**, in orange) training was based on the natural subdivision allowed by a digital game: four sessions of 20 min each, separated by a 48 h break; knowledge tests began 24 h after the last session, with the same evaluation process as for the classic training group.

Both the groups (**Figure 4**, in purple) underwent three knowledge tests about neonatal resuscitation algorithm and equipment check. The test was administered at three different times: immediately before the tutorial (pre-test 0), at 24 h (post-test 1) and at 28 days (follow-up test 2) after training ending; the questions and answers remained the same, while their order was randomly altered. Specific time intervals between assessments were chosen to capture actual knowledge retention. A 24 h post-training time interval was specifically chosen to filter out the positive effects of short-term memory on scores (24). The 28-day interval to evaluate of memory decay has been widely used in DGBL (25). Unlike a much longer interval adopted by other authors (9, 17), it minimizes the high risk of study drop out within a medical resident population, or the confounding effect of further training. Similarly, candidates were not made aware of our study's assessment methods and timings, including the 28-day delayed test, in order to prevent skewed outcomes. The three scores for either learning method were compared to evaluate the two methodologies, their strengths and limitations (comparisons 0, 1, 2 in red in **Figure 4**). Knowledge test 0 was also used to evaluate the design.

Furthermore, in DGBL group, user improvement was evaluated as the sessions progressed by recording any change in individual tests' numerical values (equipment score, procedure score, response time, ventilation frequency, compression rate) as common in DGBL methodologies (26). At the end of data collection, a user satisfaction questionnaire was administered to DGBL group, to integrate subsequent versions of the software with user suggestions.

Measures

The primary endpoint of this study is to compare the effectiveness between DGBL (DIANA) and classic learning methodology on knowledge retention based on knowledge questionnaire performance. The several secondary endpoints regarding the evaluation of the effectiveness of the DGBL methodologies on the user's performance during the gaming sessions and the satisfactions evaluation of this new methodology are summarized in **Table 1** and described in sections "Knowledge test scores" and "DGBL scores."

Knowledge Test Scores

Knowledge tests are used in DGBL analysis to evaluate performance (20). The test used in this work was written by neonatal resuscitation trainers accredited by SIN, and consisted of 21 questions (each with 1 correct and 5 incorrect answers) related to the correct resuscitation procedure and a list of 40 items (21 correct, 6 partially correct, and 13 incorrect) to check. The knowledge test score was calculated by allocating 1 point for each correct answer, 0 for null, and −0.2 for incorrect ones, so that the average score could be assumed to be zero in case of randomly selected answers. The result was then normalized by the number of questions. The equipment score, on the other hand, consisted of the number of correct instruments (21) selected from the list of 40 items.

DGBL Scores

During the execution of DIANA game, the following parameters were recorded: decision-making/response time, answer correctness from the multiple options included in the simulation, choice of equipment before each simulation, uniformity, and correctness of ventilations/compressions timing. A positive score was assigned for a correct answer, a negative value for an incorrect selection, and a neutral (null) score for selecting the *"Get help"* option, available for every

TABLE 1 | Description of the variables observed during the study divided between primary endpoints (evaluate the effectiveness of DGBL and classic learning methodology on knowledge retention) and secondary endpoints (evaluate the effectiveness on user's performance during the gaming sessions).

Comparison	Feature observed	Comparison Tool	Question to answer
DGBL (DIANA) and classic learning methodology [primary endpoint]	Knowledge retention and equipment checklist	Knowledge tests (pre-training, 1 day post, and 28 days post-training)	Did the DGBL training methodology prove as effective as theoretical teaching session in knowledge retention?
DGBL(DIANA) games performance [secondary endpoints]	Knowledge retention	Performance of different session game scores	Was the DGBL training methodology effective to learn a flowchart reducing decision time and increasing scores results?
	Equipment checklist		Was the DGBL training methodology effective to learn the equipment checklist?
	Ventilation rate		Was the DIANA ventilation game effective to learn the correct ventilation rate to perform during a PPV procedure?
	Chest compression rate		Was the DIANA chest compression game effective to learn the correct rate to perform during a newborn resuscitation?
	Satisfaction of new methodology	Satisfaction questionnaire	Has the DGBL methodology been considered useful and effective by users?

question to cover the operator's inability to make a decision. Choosing this option was followed by a detailed explanation of the correct decision by the virtual assistant to stimulate learning and improve subsequent sessions' performance. Knowledge score was calculated as the number of correct answers normalized by the number of questions for each session. The equipment score consisted of the number of correct instruments selected from a list of 40 items (21 correct, 6 partially correct, and 13 incorrect). As some game sessions covered only part of the resuscitation procedure (**Figure 1**), the knowledge score was calculated on three question subsets: on care and assisted ventilation (PPV) (sessions 1-2-3-4), on intubation and compressions (sessions 1-3-4), and those on drug administration (session 1-4), respectively. For each answer, the response time (i.e., the time elapsed between the question administration and the execution of the action) was also calculated.

Compression and Ventilation Scores

In the games involving compressions and ventilations, choosing a score that rewarded maintenance of a correct frequency and penalized frequency fluctuations was essential. The number of acts per minute is not necessarily a reliable parameter to tell an excellent performance (i.e., correct and uniform rate) from a sub-optimal one, such as correct but non-uniform rate with marked variations in frequency. With reference to **Figure 5**, we defined the sequence of acts $1, \cdots, n$ and the corresponding $\Delta_i := t_i - t_{i-1}$ as the difference between the time of act i and the time of the previous act $i - 1$. The correct timing intervals are then defined $[min_{freq}, max_{freq}]$ (40–60 ventilations per minute and 80–100 [+30] compressions per minute, where +30 represents the ventilations performed alternately by the virtual assistant). These ranges represent the reference values that the user must maintain and correspond to an interval $[min_{timing}, max_{timing}] = [1/max_{freq}, 1/min_{freq}]$ between the minimum and maximum of the time interval allowed to perform a correct number of acts per minute. Therefore, the correctness value of the ith act is defined as follows:

$$d_i := \begin{cases} 0 & \text{if } \Delta_i \in [min_{timing}, max_{timing}] \\ max\left(\left|\Delta_i - min_{timing}\right|, \left|\Delta_i - max_{timing}\right|\right) & \text{otherwise} \end{cases}$$

With reference to **Figure 5**, every act falling within the correct ranges is rated as zero, while any variation outside the range (in red in the figure) increases the score in proportion to how much it deviates from the reference values. The first score is defined as the average of the $\{d_i\}_{i=1}^n$ [e.g., $score_{mean} = mean_{i=1}^n(d_i)$]. A null score represents a candidate who has always maintained an optimal frequency of acts while a higher score identifies any deviation from the correct execution. The second score is based on the standard deviation of the $\{d_i\}_{i=1}^n$ [e.g., $score_{std} = std_{i=1}^n(d_i)$]. This score characterizes the irregularity of the values and is, therefore, indicative of maintaining a non-homogeneous timing during the test.

Ethical Approval

Users were pediatric/neonatology residents of the Azienda Ospedaliera Universitaria Pisana (AOUP) who consented to the acquisition, processing, and dissemination of data in anonymized form. The study was approved by the local Institutional Review Board for Ethic Issues. All analyzed data were anonymized and the entire analysis was blinded.

Statistical Analysis

The study design is based on a stratified random sampling to control the nuisance factors. The strata are designed on the basis of a score extrapolated from a questionnaire of previous theoretical/clinical/practical experience. This score was used to create four levels of competence (0 no experience, 1: one of the three experiences, 2: two experiences, up to 3 for those who participated in all simulation, theory, and practice experiences), then used in the study design to divide the candidates of the two groups. The uniformity of the knowledge test 0 score distributions of the two groups' clinical experience was tested using a Kolmogorov–Smirnov (KS) two-sided test. A further indicator of uniformity is the amount of times a random sampling could have produced a better subdivision

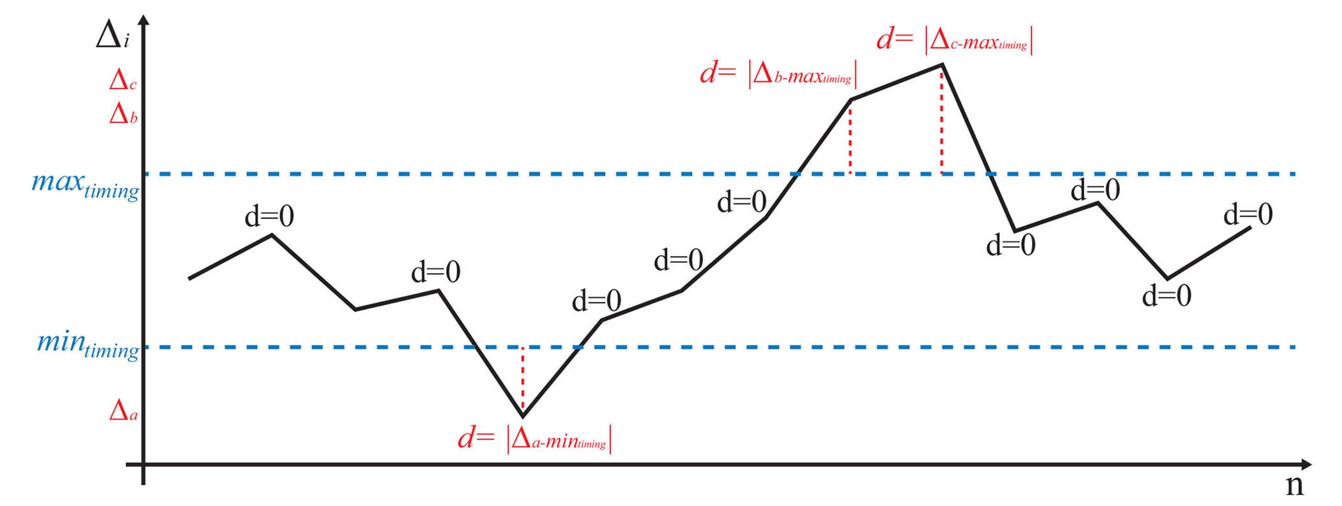

FIGURE 5 | Example of a possible of ventilation/compression pattern (black). If the Δ_i between two consecutive acts is correct, it falls between the horizontal dashed lines $y = min_{timing}$ and $y = max_{timing}$; in this case, the value is considered perfectly correct (e.g., $d = 0$). Excessively irregular patterns lead to a positive value of d (red).

than the chosen design. This estimate was achieved by using a Monte Carlo method for probability estimation: 100,000 times the group of all candidates (associated with their respective knowledge test score 0) is randomly divided into two groups (27 and 21, respectively). This (artificial) subdivision represents a possible result of a random fully experimental design. Then, the Kolmogorov–Smirnov distance D between the two sets is calculated and compared with that obtained in the stratified random sampling. The knowledge test scores calculated before learning, at the end of learning and 28 days later, were evaluated by comparing the means, variances and distributions (KS test). The normality of the scores obtained was tested by Shapiro–Wilk test. Variances were compared by F-test for (independent) groups comparison and by Pitman–Morgan test of variance for paired sample for internal group comparisons. Under the assumptions of normality and homogeneity of variances, the independent t-test was used to compare means. In the absence of these hypotheses, the non-parametric (conservative) Wilcoxon signed-rank test and the Mann–Whitney U-test were used. Considering that the scores calculated in the knowledge tests 0, 1, and 2 are repeated measures of the same group and the frequent absence of the hypothesis of normality, the values are preliminary compared using a Friedman test. Post hoc pairwise analysis through the previously described paired tests are then applied to detect variations of the score. Bonferroni correction is presented to counter the problem of multiple post hoc analysis. The comparison between independent groups (i.e., DGBL vs. theory) pre-training, at 1 day and at 28 days is instead carried out with non-paired tests. To analyze the performance of the individual game sessions, the same tests were applied to learning score procedure, the response times of the questions, and the uniformity of the ventilation/compression timing. One-sided versions of the tests were applied to test the monotony of the scores. Statistical analysis was carried out using the software R [4.1.1] (27).

RESULTS

Participant Characteristics and Stratified Random Sampling

Sixty-three pediatric/neonatology residents from the Azienda Ospedaliera Universitaria Pisana (AOUP) were recruited for the study, ranging from the first to the fifth specialty year with a high variability in previous training. The level of competence of each resident depends on the experience acquired before the start of the analysis (year of specialty, practice using a simulator, having attended theoretical training, and also real clinical practice with newborns). These nuisance variables (i.e., a variable that may alter the outcome of the study but is of limited interest in the chosen design) were of no interest to the study and had to be controlled to ensure homogeneity of the two groups using the stratified random sampling. By applying the Monte Carlo approach against the Kolmogorov–Smirnov distance calculated with the chosen design ($d = 0.13$), only 8% of the random subdivisions thus generated show a distance $D < d = 0.13$, confirming the validity of the design used.

Furthermore, the validity of the study design was tested also by comparing the knowledge test 0 and the check equipment scores between the two groups: no statistically significant differences were found (two-sided Mann–Whitney U-test $p = 0.21 \gg 0.05$ and two-sided independent t-test $p = 0.51 \gg 0.05$ for equipment score). Furthermore, the distributions of both values were also not dissimilar (two-sided Kolmogorov–Smirnov test, $p \gg 0.5$). The experiment design, and the corresponding subdivision of the population in strata, allowed to obtain a homogeneous level of past experience (as shown by the level of competence in **Figure 6**). The two groups were therefore considered uniform in the baseline scores (knowledge test 0) and homogeneously subdivided according to the confounding variables.

The design led to two groups uniform in terms of previous experiences (**Figure 7**). Candidates who dropped out for personal

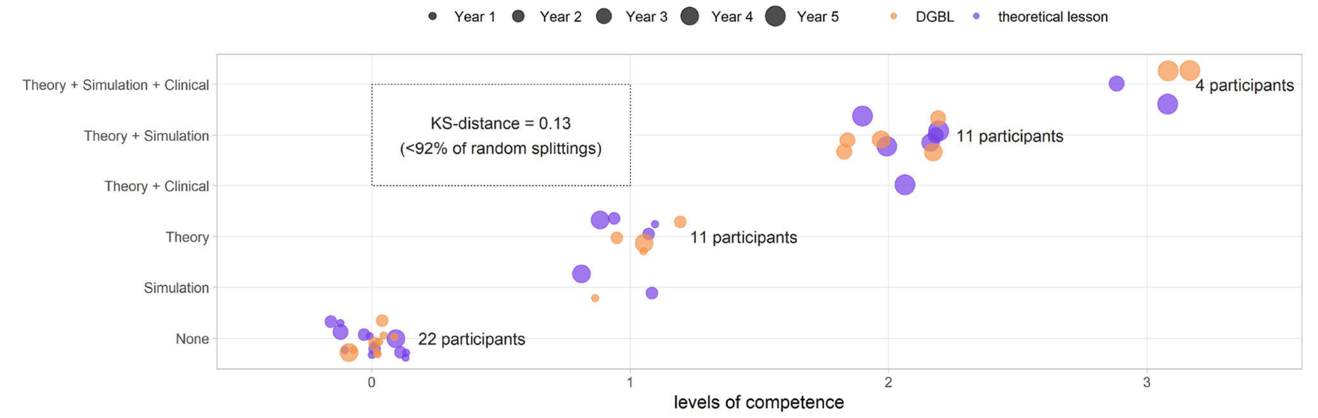

FIGURE 6 | Group subdivision based on competence levels for the stratified random sampling (digital game based learning [DGBL] group in orange, theoretical teaching session group in purple). Using a Monte Carlo approach based on the knowledge test 0 score and the Kolmogorov–Smirnov distance, it can be shown that this subdivision is better than 92% of those artificially obtained through a fully random design.

reasons, or those failed to meet learning and testing sessions deadlines, were excluded from the study: of a total of 15, the majority affected DGBL group, yielding 27 candidates for the classic learning group and 21 for DGBL group. In the breakdown of the study sample by specialty year, 56% of the residents clustered around first and second year (**Figure 7A**), only 35.3% of the trainees had practiced at the simulator before this study (**Figure 7B**), whereas 47.9% had already received theoretical training in neonatal resuscitation (**Figure 7C**). User characteristics that could significantly impact results (e.g., neonatal clinical experience, as shown in **Figure 7D**) were uncommon in this cohort (only 10.3% of candidates); this setting required a proper design in order to prevent concentrating the few candidates with any particular characteristic in only one of the two groups. Consequently, the reference sample can be described as having a dominant component of students of the first years, mostly with no previous experience (45.8%). The older residents were the ones with greater medical experience (clinical/simulation/theoretical), with all fifth-years students having received at least one theoretical teaching session and one practical tutorial at the simulator.

Comparison Between DGBL and Classic Learning

Knowledge Retention

The first analysis was based on the scores obtained in the knowledge tests 0, 1, 2 (respectively, pre-training, 1 day post-test, and 28 days later follow-up). None of the observed test score distributions could be assumed to be normal except pre-training scores (Shapiro–Wilk test, $\alpha = 0.05$) as shown in **Figure 8** (purple for classic learning and orange for DGBL approach).

After a preliminary Friedman test ($\alpha = 0.05$) that found differences in scores between the knowledge tests 0, 1, 2 for both the DGBL ($p \ll 0.001$) and the theoretical training ($p \ll 0.001$), we moved on to the post-hoc pairwise analysis. The effectiveness of the theoretical teaching session was proved by an increase in pre-training and post-training tested scores at 1 day, with an increase in median scores from 42.8 to 71.4% (paired one-sided Wilcoxon signed-rank test, $p \ll = 0.001$). An even greater increase in scores was found for DGBL training, with median scores ranging from 42.8% pre-training to 83.8% post-training (paired one-sided Wilcoxon signed-rank test, $p \ll 0.001$). There was no statistically significant reduction in scores following the 28-day wait ($\alpha = 0.05$). Even considering a conservative Bonferroni correction factor ($m = 2$) to control the family-wise error rate, the reported results have much lower p-values than the corrected $\tilde{\alpha} = \alpha/m = 0.025$. The initial pre-training scores could be considered coincident both as medians (two-sided Mann–Whitney U-test, $p = 0.21 \gg \alpha = 0.05$) and as distributions (two-sided Kolmogorov–Smirnov test, $p = 0.97 \gg \alpha = 0.05$). This allowed to compare the score increases for the two methodologies. Therefore, considering the post-/pre-training score differences, DGBL method was statistically not inferior to the classic teaching session (one-sided Mann–Whitney U-test, $p = 0.005$). As represented graphically in **Figure 8** (28 days), score variance decreased between pre-training and post-training (1 day) for both methodologies (one-sided paired Pitman–Morgan test, $p \ll \alpha = 0.001$). There was no statistically significant variance increase 28 days post-learning for DGBL group ($p = 0.07 > \alpha = 0.05$), while variance increased significantly for the classic methodology group ($p = 0.02 < \alpha = 0.05$). Furthermore, the variance at 28 days for the classic learning group was greater than that of DGBL group, with values more distributed over the score range (one-sided F-test, $p = 0.03 < \alpha = 0.05$). The variance of the analyzed scores makes it possible to distinguish between a population with a homogeneous knowledge (low variance) compared to one with marked differences between the scores of the individuals (high variance). For this reason, we want to investigate whether following learning there is a simple increase in scores, which is an indication of an effective transmission of knowledge, or even a consequent reduction in the variance of scores, that is representative of uniformity of skills following

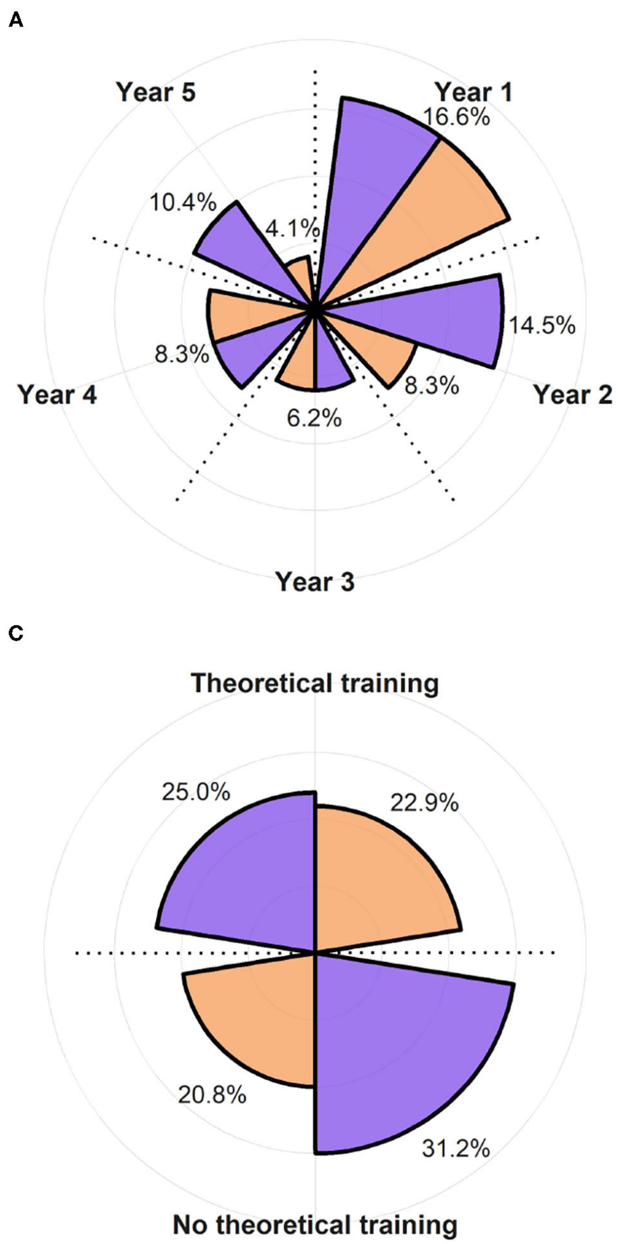

FIGURE 7 | Subdivision of the population of the study between DGBL group (in orange) and classic theoretical teaching group (in purple). **(A)** Shows the year of specialty training (not one of the variables considered in the stratified random sampling) and is therefore characterized by a higher variability. **(B–D)** Show the percentage of the subjects that had used a newborn clinical simulator, underwent theoretical training in neonatal resuscitation, and practiced in neonatology, respectively.

learning (e.g., we were able to teach them what we wanted to teach them).

Equipment Game

Equipment scores were divided into three categories: totally correct, partially correct, and incorrect. Learning was considered to be effective if users selected a greater number of correct options and fewer of the incorrect/partially correct ones. The scores evaluated at steps 0, 1, 2 (respectively, pre-training, 1 day post-training, 28 days follow-up) of classic learning (in purple, **Figure 9A**) and DGBL methodology (in orange, **Figure 9B**) are shown in **Figure 9**. All the score distributions were non-normal, except scores for the correct tools at the 0/pre-training evaluation (Shapiro–Wilk, $\alpha = 0.05$). A preliminary Friedman

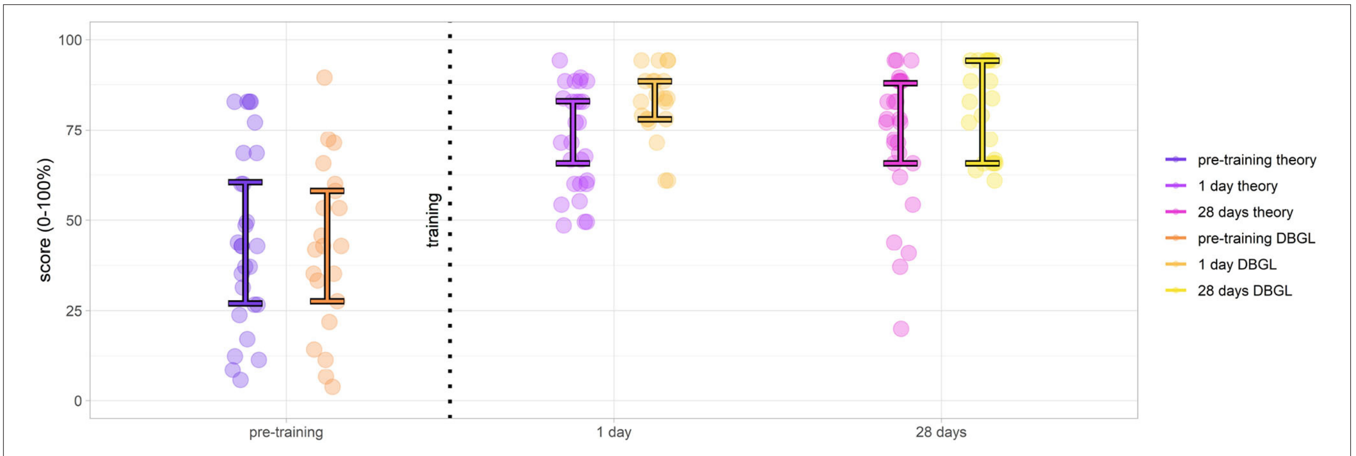

FIGURE 8 | Results of knowledge tests evaluated pre-training, 1 day post-training, and at 28 days follow-up (score medians and middle 50% interquartile ([0.25, 0.75]); theoretical teaching session group scores in purple, digital game based learning (DGBL) method group scores in orange). Although pre-training groups are comparable, post-training scores demonstrate the effectiveness of both methodologies and DGBL, in particular.

FIGURE 9 | Equipment scores of totally correct/partially correct and incorrect items selected by the control group (standard teaching session, **A**) and digital game based learning (DGBL) group **(B)**. Initial equipment scores for the two methodologies are not statistically different. DGBL methodology leads to a greater increase in correct item selection. It also reduces selection of incorrect/partially correct items, whereas after theoretical teaching no reduction is observed.

test ($\alpha = 0.05$) is performed to detect if there is a difference among the three assessments (knowledge test 0, 1, 2) for both DGB/classic learning and for the totally/partially correct and incorrect items. A statistical significance of the learning effect is only found for the totally correct items (classical theoretical learning, $p = 0.02$) and for both totally correct ($p \ll 0.001$) and incorrect ($p = 0.007$) items score for the DGBL training. Classic learning (**Figure 9A**) was effective in achieving memorization of totally correct objects (57.1 to 71.4%, paired one-sided Wilcoxon signed-rank test con $p \ll 0.001$). No other statistically significant improvement ($\alpha = 0.05$) was noted in any of the other scores, either in relation to the 1 or 28-day assessment. Conversely, there was an increase in the partially correct objects chosen in Test 1 (33.3 to 50.0%, $p = 0.01$). The DGBL methodology proved more effective (**Figure 9B**), with not only a statistically significant improvement in pre-training/ 1-day scores for correct items (57.1 to 90.5%, paired one-sided Wilcoxon signed-rank test con $p \ll 0.001$), but also with a moderate a reduction of incorrect items (23.1 to 15.4%, $p = 0.03$), which is not statistically relevant for the classical learning method. The initial scores for the correct objects coincide for the two groups for both the median (57.1%, paired two-sided Wilcoxon signed-rank test con $p = 0.72 \gg 0.05$) and the mean values (59.2% theoretical teaching session, 56.7% DGBL, two-sided independent t-test, $p = 0.51 \gg \alpha = 0.05$). As the coinciding baselines allow an analysis of the pre-/post-training differences of the two groups, the DGBL methodology led to a significantly greater improvement than the classic learning one (one-sided Mann–Whitney U-test, $p = 0.009 < \alpha = 0.05$). We did not carry out the same analysis for partially correct and incorrect objects, as uniformity between the two strategies cannot be assumed at the $\alpha = 0.05$ level. In this analysis, considering a Bonferroni correction factor ($m = 2$) did not change the result of the effect of training on score of correct items. However, the effect of the reduction of incorrect items for the DGLB group can no longer be considered statistically significant.

Item Choice in Equipment Check

With regard to the total number of times that each tool was selected during the knowledge tests (regardless of the learning mode), training methodology can be improved. Indeed, **Figure 10** highlights the elements for which the methodology worked well (increasing values for totally correct from the center outwards, and decreasing for partially correct/incorrect ones) and those for which it does not (stable scores among the sessions). For almost all totally correct options, learning proved effective with both methodologies; however, some options were too obviously correct, e.g., adrenaline administration (45–47/47) or pulse oximeter use (41–40/44). The best training effect was seen on discouraging the selection of endotracheal tubes (ET) (0, 1) (30–19/17). For other incorrect items (intensive care ventilator, E.R. Bag, E.T. tube size) and partially correct ones [laryngeal mask airway (31–33/33), check neonatal incubator (37–43/43), E.R. bag (20–18/15), and intensive care ventilator (19–25/27)], the learning was not effective enough, as users continued to rate them as necessary despite training indicating otherwise. We are planning the implementation of software changes, which will allow to investigate communication effectiveness for these learning objectives. It should be emphasized that some incorrect tools [ultrasound machine, ultrasound probe, LISAcath(R)] proved poor distractors, as users hardly ever selected them. Therefore, future versions of the game will not include those items.

DGBL Game Performance

Knowledge Retention

Figure 11A shows the scores and the respective averages of the game sessions (e.g., the number of correct answers) by category and session number (1, 2, 3, 4). The medians response times (seconds) for the entire corresponding series of questions are shown in **Figure 11B**. After three preliminary Friedman tests for scoring (CARE and PPV, intubation and chest compression, and drug administration) and three more for answer times ($\alpha = 0.05$), all identifying a statistical difference, we moved on to post hoc pairwise analysis. Both panels show a strong monotonicity in the functions, with increasing scores ($\sim$ 65.3 to 96.7) and decreasing times ($\sim$ 11.9 to 7.7 s) as the sessions progress (one sided paired Wilcoxon signed-rank test, $\alpha = 0.05$), except for equipment CARE and PPV/intubation and chest compression scores between session 3 and session 4 ($\alpha = 0.05$), which did not show a statistically significant increase (knowledge plateau). After a Bonferroni correction by a factor ($m = 5$) for the CARE and PPV and a factor 3 for intubation and chest compression, the same results remained valid at a level of $\tilde{\alpha} = \alpha/m = 0.01$ except for the CARE and PPV scores between session 2 and 3, whose increase was no longer statistically significant. Test values at sessions 1 and 4 highly correlate ($\rho = 0.84$, Pearson test for linear correlation $p \ll 0.001$) with knowledge test scores 0 and 4. The game scores are therefore predictive of success in the following knowledge test.

Equipment Game

As anticipated by knowledge tests (**Figure 8**), the sessions improve users' ability to choose the correct objects. Indeed, the number of totally correct objects selected (**Figure 12A**) and partially correct/incorrect ones (**Figure 12B**), respectively, increased and decreased after each session. Specifically, since all the scores are not normal (Shapiro–Wilk test at the alpha level = 0.05), we proceeded to test the monotony of the score with a non-parametric test (preliminary Friedman test at a level $\alpha = 0.05$ that revealed a statistical difference between the totally correct scores, and *post-hoc* one-sided paired Wilcoxon signed-rank test, respectively, $p \ll 0.001, p = 0.01, p = 0.003$ between sessions 1–2, 2–3, and 3–4). Unlike procedure memorization highlighted by the scores (**Figure 11**), there is still a statistically significant improvement for this game between sessions 3 and 4 ($p = 0.003$). A Bonferroni correction factor $m = 5$, the number of pairwise analysis carried out, can be applied ($\tilde{\alpha} = \alpha/m = 0.01$). Despite the correction, the results presented remain unchanged. Furthermore, candidates made fewer mistakes when the tool name was paired with its picture (medians of 0 for partially correct items and incorrect ones vs. 33.3 and 15.4% for the same students during the knowledge test), as shown in **Figures 12B**, **9B**, respectively.

Ventilation and Compression Game

Figure 13 shows the deviation from the correct ventilation (40–60 breaths per minute = intervals between 100 and 150

FIGURE 10 | Number of items selected by users (regardless of learning mode) during the knowledge tests, divided by color into incorrect (red), partially correct (yellow), and totally correct (green). Greater color opacity indicates a greater number of selected items. Selected elements numbers are subdivided as pre-training (inner circle), 1-day post-training (middle circle), and at 28 days follow-up (outer circle). Color opacity shifts highlight the items for which learning has proved particularly effective (e.g., ECG leads that go from 27 pre-training to 38/33 post-training or ET tubes (size 2.5, 3, 3.5) that are reduced from 30 to 19/17), whereas uniformity of color opacity across the concentric circles show the items for which learning has proved ineffective (e.g., intensive care ventilator, laryngeal mask airway, or check neonatal incubator).

hundredths of a second) and compression ranges (80–100 breaths per minute = considering 30 alternating breaths per minute, intervals between acts of 46–54 hundredths of a second). The score (Y axis) represents the precision of execution in terms of number of acts, a score of 0 representing a frequency kept within the range. Circle size is the standard deviation (STD) of the uniformity score d. Smaller circles represent greater execution uniformity. Ventilation frequency was not as effectively learned as compression rate, despite the apparent similarity of the games aiming to teach them (**Figures 13A,B**, respectively). From a

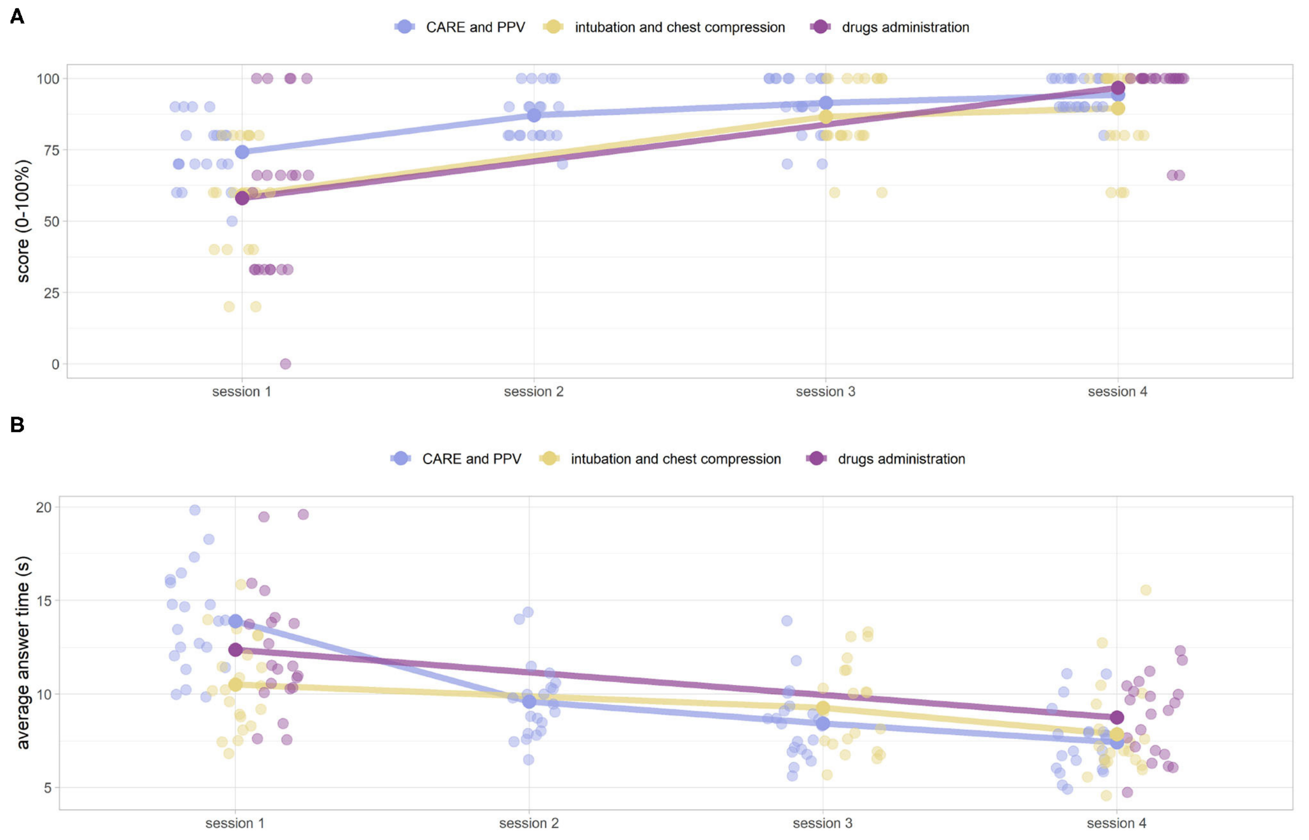

FIGURE 11 | (A) DIgital Application in Newborn Assessment (DIANA) game scores, and corresponding median values, over the four sessions. The scores are subdivided into three categories (CARE and PPV, intubation and chest compressions, drugs administration) for ease of analysis. **(B)** Corresponding average answer times (in seconds).

statistical point of view, the values of the scores and the STDs of the rates all follow non-normal distributions (Shapiro–Wilk test, $p < 0.001$ for scores and $p < 0.01$ for STDs). Regarding the ventilations there is an improvement of both parameters. Score values are decreasing with monotony (one tailed Wilcoxon signed-rank test $p < 0.01$). With regard to STDs, on the other hand, there is a statistically significant reduction between the first/second session ($p = 0.03$) and the third/fourth session ($p = 0.001$) but not between the second/third. The same tests, applied to compressions, were all statistically inconclusive.

Satisfaction Questionnaires

Of the data collected from DGBL user satisfaction questionnaires (20/21), we evaluated perceived utility and enjoyment of the procedure (both using a five-level Likert scale). Ratings were generally positive in terms of perceived utility [40% (5/5) and 60% (4/5)] and procedure agreeableness [40% (5/5) and 60% (4/5)]. Suggestions mainly concerned the need to increase available equipment game time, perceived as too short. Positive feedback was given on spreading the game sessions over different days.

DISCUSSION

This study successfully applied a DGBL-based approach to neonatal resuscitation teaching through the use of a newly developed software (DIANA). DIANA game focused on the entire neonatal resuscitation algorithm (including equipment check, neonatal care, drug administration, assisted ventilation, and chest compressions). The study was aimed at pediatric/neonatology residents [a learners' category considered in few studies as in the mixed study group by (12)], while the majority of previous findings in this field have focused on undergraduate medical students (9, 19, 20), healthcare professionals (11, 12, 21), and experienced neonatal providers (17, 21). This study's sample size is similar to other DGBL studies in the medical/neonatal field (9, 10, 17, 28, 29). Learner allocation (Stratified random sampling) to two experience-based groups (year of specialty training, previous theoretical teaching session, simulation experience, clinical practice experience) proved effective in obtaining homogeneous baseline scores (Section 3.1). Furthermore, the subdivision obtained was better than 92% of those eventually obtained by applying a completely random method. This study is among the few that (1) fully exploit the ability of a game to extract user data (e.g., ventilation/compression game scores, response time, etc.), (2) define a treatment group and an independent control group through a baseline score (pre-test), and (3) evaluate two follow-ups (short- and long-term knowledge retention). In addition, compared with the majority of published studies, which tested learner months apart (9, 10, 17), we preferred to keep the testing

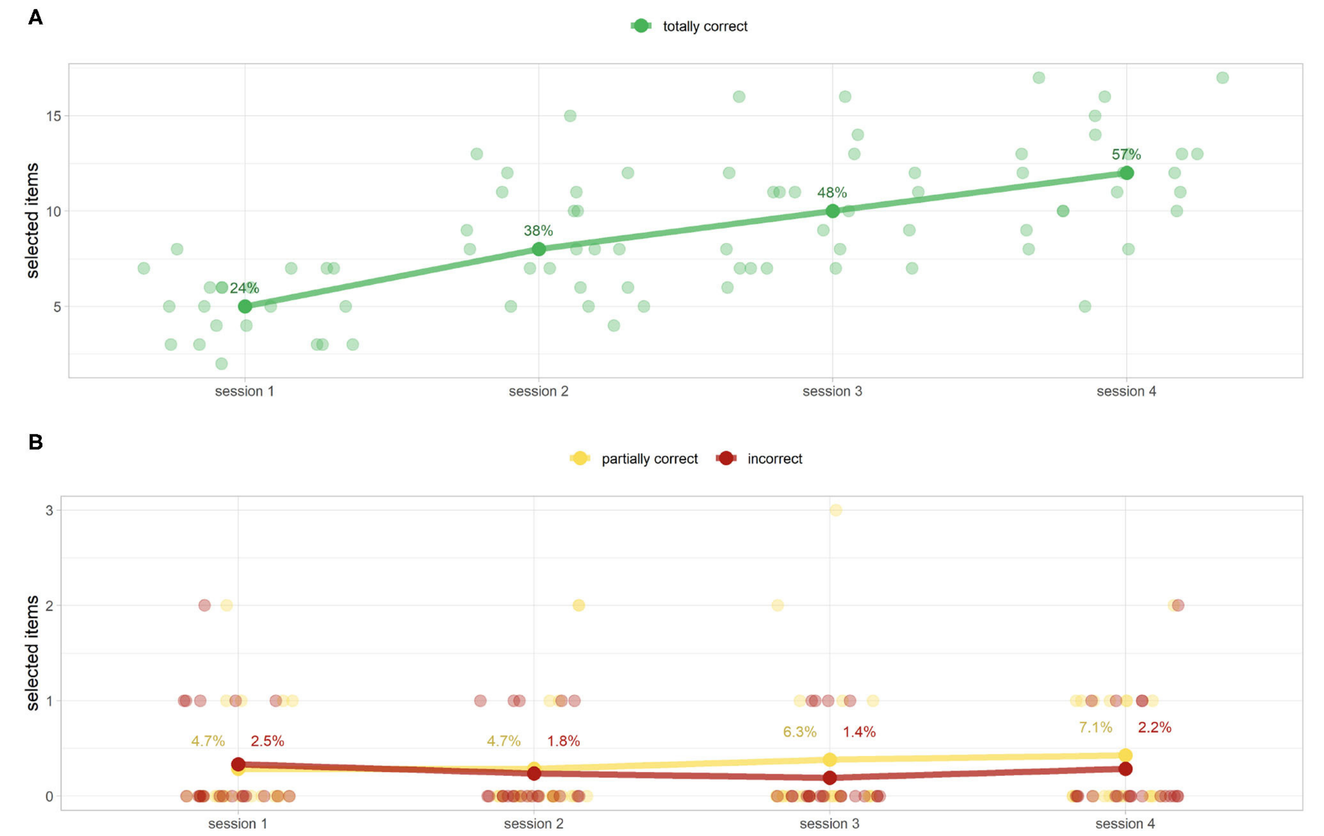

FIGURE 12 | DIgital Application in Newborn Assessment (DIANA) game equipment scores (as selected items and their percentage of the median of total items) for totally correct **(A)** and partially correct/incorrect items **(B)**. **(A)** Shows a monotonous increase of correctly chosen elements (from 24 to 56%). **(B)** Shows extremely low values of partially correct/incorrect scores. This finding reinforces the idea that visual memory plays a pivotal role in memorization. **(B)** Shows the percentage of the mean values because the corresponding medians are all equal to 0.

interval shorter [and yet longer than 2 weeks, in line with best practice in assessing DGBL learning (30)]; as the studied cohort was recruited among pediatric/neonatology residents, specialty training would invariably continue to provide reinforcement of the skills assessed. It should be noted that 28 days are considered a sufficient timeframe to evaluate memorization of a procedure in the medium to long term (25).

The DGBL methodology proved to be useful and appreciated by users to teach both neonatal resuscitation algorithm and ventilation execution. Furthermore, it proved to be even more effective than the classic frontal teaching session for both short-term procedure memorization and equipment game score. In particular, the scores related to short-term knowledge retention proved to be higher than those obtained by the theoretical frontal teaching session, in line with the existing literature (10, 19, 20). Also in line with the limited number of studies with a follow-up at more than 28 days (9, 10, 17), long-term knowledge retention for DGBL group was as good as the control group one. Furthermore, candidates who had received classic training demonstrated a regression to lower scores, unlike DGBL methodology learners. DGBL methodology was particularly effective in the learning of clinical equipment checking. Although the classic theory teaching session led to a statistically significant, but moderate increase in the number of correct objects chosen (57.1–71.4%), DGBL-based approach led to a much greater improvement (57.1–90.5%). Furthermore, while the classic teaching session had almost no effect on changing the scores for partially correct/incorrect items (33.1–50.0 and 23.1–15.4%), DIANA game reduced or leave unchanged scores for both partially correct (33.1–33.1%) and incorrect tools (23.1–15.4%). This score discrepancy is likely due to the difference in the way the learning objective is conveyed: DGBL approach breaks learning into sub-games (one of which is the explicit teaching of which tools should be used), while during a theory teaching session the tools are named progressively at the time of their use. Overall, the DGBL methodology subdivision of learning into multiple sessions was confirmed to be effective for the learning of neonatal resuscitation in line with further previous simulation-based studies (28, 29), especially for the maintenance of the acquired competencies (31). The information collected in the DGBL sessions allows performance analysis (learning curve) related to flowchart learning, response times, equipment check, and timing of assisted ventilations/chest compressions. Procedure learning was effectively achieved, in line with the existing literature (9, 17, 21): the first three sessions

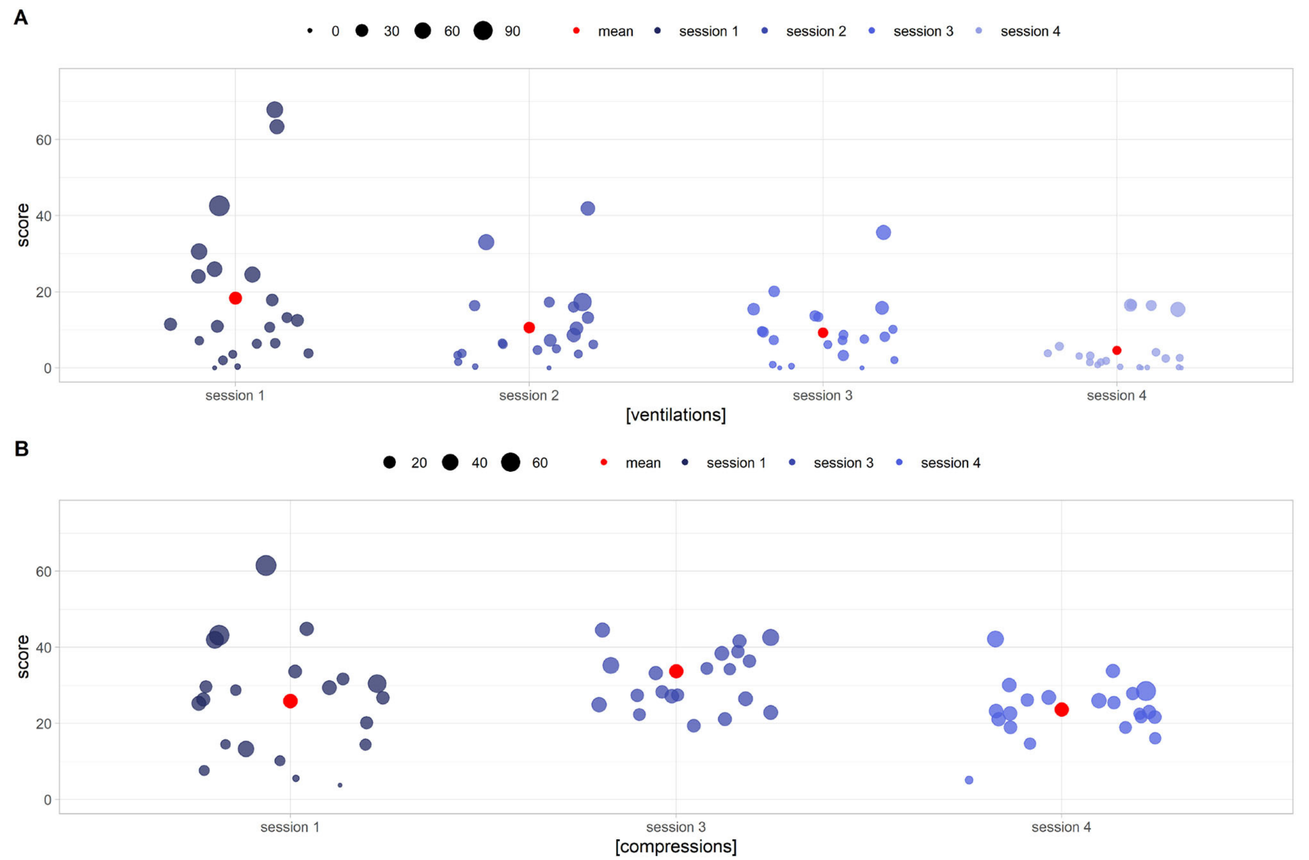

FIGURE 13 | DIgital Application in Newborn Assessment (DIANA) game scores (y axis) and standard deviation (circle size) for ventilation **(A)** and chest compression **(B)** execution. Low y values imply an execution frequency closer to the correct one, while short circle radii identify smoother acts. **(A)** Shows performance improvement in terms of both correct frequency (decreasing score to 0) and smoothness of execution (small circles radii). **(B)** Shows a less noticeable improvement in performance, with users still unable to execute compressions correctly after the fourth session.

showed significant improvements in learning, while the fourth highlighted a learning plateau. Of note, there was a constant improvement in response times along the four sessions, with a total reduction of more than 30% of the initial one. Similarly, there was a steady improvement in the correct equipment check score (from 24 to 57%). In the assisted ventilation game, DGBL methodology proved to be effective, as residents responded to the feedback from the game and learned to keep the correct rate independently. However, in the chest compressions game, similar in execution to the assisted ventilation one, we did not observe the same effectiveness; candidates did not improve in either the frequency (remaining outside the required clinical range) or the regularity of compressions. This pattern persisted across all four sessions. The discrepancy between these two results could be induced by the differences between the two games. Indeed, during the compression game, the user must interact with the virtual assistant which performs ventilation. To complete the task before next the ventilation, users tend to perform excessively clustered and irregular compressions. To facilitate the reading of the discussion presented above, the results and consequences of the study are shown in **Table 2**.

The administration of a user satisfaction questionnaire confirmed a greater appreciation for DGBL as a training methodology than the classic frontal theory teaching session, in line with the existing literature (13, 19, 20). DGBL methodology usability is crucial for future developments, as learners positively disposed to digital tools tend to respond more effectively (26). Based on the satisfaction questionnaire results, appreciation was lower for the check equipment game compared to the others, despite its effectiveness on improving user scoring.

One of the limitations of this study is the inability of digital software to teach the execution of technical skills. Particularly for complex tasks (also to be combined with another operator), such as chest compressions, this methodology proved ineffective: users' acts remained too frequent, inappropriately clustered and not coordinated with the virtual assistant. Furthermore, the knowledge test does not guarantee that users will apply those skills effectively in a clinical context. Future versions of this software will be developed from the analysis presented in this study and the suggestions collected through the satisfaction questionnaire. Specifically, we aim to reduce the number of sessions to 3 (learning plateau detected at the fourth one),

TABLE 2 | Summary of study results.

Comparison	Results
Primary endpoint	The DGBL methodology proved to be even more effective than the classic frontal teaching session for both short-term procedure memorization and equipment game score. Long-term knowledge retention for the DGBL group was as good as that of the control group (classical training).
Secondary endpoints	The answer time (seconds) decreased after each session. The score of the games increased for the first three sessions and then reached a plateau.
	The sessions improved users' ability to choose the correct equipment.
	There was a statistically significant improvement in the execution (rate) of ventilation after each session.
	There was no statistically significant improvement in the execution (rate) of chest compression
	Ratings were positive in terms of perceived utility and procedure agreeableness.

allow no time limitation for the equipment check game, and exclude from the tool list the obviously incorrect options (poor distractors). To overcome the limitation of learning technical skills in DGBL methodology, future developments may require integration with a physical support structure to allow the candidate to practice clinical tasks. To improve the application of these training methodologies, we are developing the online implementation of DIANA (both in Italian and English) to allow the autonomous use of DIANA in further medical realities, as a free tool for training and re-training. Because of the online platform, we are already extending the same analysis on a wider population. In this way, we can use our findings (on both population characteristics and expected scores) to estimate the required sample size to improve future studies. The future development of a hardware device for the execution of practical skills will also allow to overcome a known limitation in simulation field (i.e., by lack of a report on the technical performance of the user with high-fidelity mannequins). A high-fidelity simulator could offer a report on the correct execution of the flowchart based on human external observation of simulation. However, with a hardware device designed to record the events performed, both in terms of decision-making and practical performance, it will be possible to conduct a more detailed and precise study of the effectiveness of these two training methodologies.

We will also seek to modify the software with/without hardware integration to widen the potential user base, including other clinical specialties and varying levels of experience. In particular, we aim to extend this learning tool to users less accustomed to digital technology to further assess the impact of user mindset on the effectiveness of DGBL methodology (26). Moreover, as DGBL is unlikely to be adopted as a stand-alone teaching method (11) [especially in higher education (14)], future research may involve using the two methods in sequence, e.g., reinforcing the classic theory teaching session by DGBL, or a simulator-based introduction to a classic teaching session. This blended approach has been already validated for simulations outside neonatology (32). Considering the positive feedback obtained by remotely testing DGBL in other healthcare education contexts (17), deployment of DGBL to support healthcare education in low-income countries could represent another future development in the use of this learning technology.

CONCLUSION

In this study, DGBL methodology for pediatric/neonatology resident training proved to be superior to theoretical teaching session (led by a neonatal expert trainer) on short- and long-term knowledge retention of memorization of the correct equipment to assemble. In addition, DGBL proved to be at least as effective as the teaching lesson for memorization and retention of neonatal resuscitation algorithm. DIANA game allows individual user session analysis, with an improvement in "session-after-session" scores and a reduction in decision-making times. We propose that DGBL could be a valuable addition to classic learning methodology for all medical procedures involving a procedural algorithm.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Dipartimento Materno-Infantile, Azienda Ospedaliero Universitaria Pisana. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

SB fully implemented the software DIANA, collected the data, drafted the initial manuscript, reviewed, and revised the manuscript. GD designed the study and the data collection tools, analyzed the data, carried out statistical analysis, drafted the initial manuscript, reviewed, and revised the manuscript. MD and FL collected the data, were involved in the classic training sessions, and revised the manuscript. RTS, MC, and AC wrote the knowledge test, taught during the classic training sessions, integrated the analysis with the corresponding medical discussion, and reviewed and revised the manuscript. NF reviewed, critically analyzed, and revised the manuscript including revision of English language. All authors contributed to the article and approved the submitted version.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fped.2022.842302/full#supplementary-material

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Advanced Clinical Neonatal Nursing Students' Transfer of Performance: From Skills Training With Real-Time Feedback on Ventilation to a Simulated Neonatal Resuscitation Scenario

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Background: Advanced clinical neonatal nurses are expected to have technical skills including bag-mask ventilation. Previous studies on neonatal bag-mask ventilation skills training focus largely on medical students and/or physicians. The aim of this study was to investigate whether advanced clinical neonatal nursing students' bag-mask ventilation training with real-time feedback resulted in transfer of bag-mask ventilation performance to a simulated setting without feedback on ventilation.

Materials and Methods: Students in advanced clinical neonatal nursing practiced bag-mask ventilation on a premature manikin (Premature Anne, Laerdal Medical, Stavanger, Norway) during skills training. A flow sensor (Neo Training, Monivent AB, Gothenburg, Sweden) was placed between the facemask and the self-inflating bag (Laerdal Medical), and visual feedback on mask leak (%), expiratory tidal volume (VT_e in ml/kg), ventilation rate and inflation pressure was provided. Two months later, the students participated in a simulated neonatal resuscitation scenario. The same variables were recorded, but not fed back to the students. We compared ventilation data from skills- and simulation training. A structured questionnaire was used to investigate the students' self-perceived neonatal ventilation competence before and after the skills- and simulation training.

Results: Mask leakage and ventilation rate was higher, and VT_e lower and highly variable in the simulated scenario compared with skills training (all $p < 0.001$). There was no statistically significant difference in inflation pressure ($p = 0.92$). The fraction of ventilations with VT_e within the target range was lower during simulation (21%) compared to skills training (30%) ($p < 0.001$). There was no difference in the students' self-perceived competence in bag-mask ventilation before vs. after skills- and simulation training.

Conclusion: Skills training with real-time feedback on mask leak, ventilation rate, tidal volume, and inflation pressure did not result in objective or subjective improvements in bag-mask ventilation in a simulated neonatal resuscitation situation. Incorrect VT_e delivery was common even when feedback was provided. It would be of interest to study whether more frequent training, and training both with and without feedback, could improve transfer of performance to a simulated resuscitation setting.

Keywords: advanced neonatal nursing education, resuscitation, real-time feedback, simulation, bag-mask ventilation

INTRODUCTION

When a newborn infant needs stabilization and resuscitation, the advanced clinical neonatal nurse participates in the team. There are three intrinsic elements of human performance in these situations: 1. technical skills; and non-technical, i.e., 2. Cognitive, and 3. behavioral skills. According to the "sociotechnical systems" theory, these elements are to some extent inseparable from each other (1–4). A concept related to the sociotechnical systems theory is the "human factor" aspect, which can be attributed to the individual, team, or the way individuals interact with the environment (5, 6). At the individual level, extensively studied human factors include cognition, fatigue, and physical ability (7). Healthcare professionals' performance in neonatal resuscitation depends on cognitive- and technical skills, as well as human factors (8).

Although, airway management is often the responsibility of physicians and respiratory therapists, the advanced clinical neonatal nurse is expected and required to have the knowledge, technical and non-technical skills, and execute physical and mental tasks, actions, and functions as a part of the resuscitation team. However, studies have shown that even experienced healthcare professionals have problems performing correct bag-mask ventilation (9, 10). Challenges include mask leakage, too low or high ventilation rate, and variable delivery of volume and pressure to the lungs (9). Both under- and over-delivery of volumes and pressures to the lungs may be harmful, causing prolonged hypoxia and bradycardia, and lung overdistension (volu- and barotrauma) and hypocapnia, respectively (11). The risk of negative long-term consequences of inappropriate ventilation may be particularly pronounced in premature infants because their lungs are immature and surfactant deficient, and their brains more vulnerable to fluctuations in blood carbon dioxide partial pressure (9, 11).

The International Liaison Committee on Resuscitation recommends programs that include simulation training with feedback from different sources including devices such as respiratory monitoring devices (12). Real-time feedback may prompt healthcare professionals to focusing on reducing mask leak and optimizing ventilation rate, tidal volume and inflation pressure, as well as provide faster learning (13) and improve the quality of resuscitation (14). During simulated neonatal cardiopulmonary resuscitation, respiratory monitoring devices, and verbal feedback were helpful methods to reduce mask leak and increase tidal volume significantly (15). Feedback on expired tidal volume (VT_e) and ventilation pressure helps to identify the need to make adjustments in the mask position or in the positioning of the infant, and may also aid the identification of airway obstruction and changes in lung compliance (14). A recent randomized crossover simulation study found that real-time feedback improved the quality of pediatric resuscitation performed by medical students, neonatal fellows and consultants, and *one* nurse (10), reinforcing that studies on bag-mask ventilation skills training focus largely on medical students and physicians.

Thus, the objective of this study was to investigate whether bag-mask ventilation skills training with real-time feedback on mask leak, delivered tidal volume, ventilation rate, and inflation pressure, enabled students in advanced clinical neonatal nursing to perform high-quality bag-mask ventilation in a simulated neonatal resuscitation scenario.

MATERIALS AND METHODS

Context and Setting

Students in the master's degree program normally participate in simulation training every half-term, but due to the Covid pandemic, the first-term simulation training was replaced with an online training case, using a video-recorded simulated scenario. This present project was conducted in the second half-term of the master's degree program in advanced clinical neonatal nursing. Skills and simulation training took place in the simulation room at Lovisenberg Diaconal University College (LDUC), Oslo, Norway.

Participants and Ethics

The requirement for admission to the master's degree program is a completed Bachelor's degree in nursing. Additionally, students must have at least 2 years of full-time postgraduate nursing experience, including minimum 1 year of full-time experience relevant to the program. Norwegian neonatal intensive care units (NICUs) are classified based on the level of medical treatment and neonatal care that they provide (16). The students in this study worked in category 3a units (cares for sick term infants and premature infants with gestational ages $\geq 28 + 0$, usually $> 1{,}200$ grams), 3b units (cares for sick term infants and premature

Abbreviations: VT_e, expiratory tidal volume; NICU, neonatal intensive care unit; LDUC, Lovisenberg Diaconal University College; IQR, interquartile range; CPR, cardiopulmonary resuscitation.

infants with gestational ages ≥ 26 + 0, usually > 900 grams) and 3c units (cares for sick term infants and premature infants with gestational ages ≥ 23 + 0).

The project was approved by the head of the faculty at LDUC and the Norwegian Center for Research Data (NSD). All students at the master's degree program in advanced clinical neonatal nursing received oral information and a written invitation to participate in the study, and the participating students gave their written consent.

Monivent Neo Training

The Neo Training system (Monivent AB, Gothenburg, Sweden) is designed to support neonatal ventilation skills training, and improve and maintain manual ventilation skills (17). Monivent Neo Training measures flow via a sensor module connected as a spacer between the manual ventilation device and a facemask. Wireless data transmission improves realism by eliminating the need for cables or pipes. The sensor module provides continuous measurements that are fed back as ventilation parameters including mask leakage, tidal volume, ventilation rate, and inflation pressure. Real-time feedback is displayed numerically and graphically on an external monitor/tablet. A color indicator on the monitor/tablet and on the sensormodule shows whether the *tidal volumes* are within a specified target range. The color indicator thus serves as a guide to making adjustments to improve ventilation.

Skills Training

In August 2021, the students at the master's degree program ($n = 24$) participated in training on technical skills related to bag-mask ventilation of a term and a premature manikin.

In alignment with the International Nursing Association for Clinical Simulation and Learning (INACSL) (18), learning objectives were aligned with the curriculum for the master's program in advanced clinical neonatal nursing and based on the theory of deliberate practice. Deliberate practice is a training approach where learners are given: a discrete goal to achieve, immediate feedback on their performance, and ample time for repetition to improve performance (19).

Lectures were given in advance of the skills training and focused on the guidelines for resuscitation, and theoretical and practical perspectives on neonatal ventilation. The lectures addressed how to place the face mask, definitions of effective ventilation (tidal volume 4–6 ml/kg and rate 30 min^{-1}), and ventilation corrective actions, e.g., establishment and maintenance of open airways, repositioning of the baby's head to secure a neutral position, and chin-jaw lifts to enlarge the pharynx. The ventilation skills training was organized in two sessions. In the first session, the students practiced bag-mask ventilation on a term manikin (Baby Anne, Laerdal Medical, Stavanger, Norway) to ensure that they managed basic ventilation skills prior to the commencement of the study data acquisition. This manikin has a realistic airway resistance that allows students to learn the important techniques of opening the airways and chin-jaw lifting (20). In groups of three, the students, in turn, practiced bag-mask ventilation with verbal guidance from a trained facilitator.

In the second session, i.e., the study baseline session, the students practiced one-by-one on a premature manikin (Premature Anne, Laerdal Medical, Stavanger, Norway). Each student ventilated the manikin for 3 min. During this session, they got visual real-time feedback on ventilation using the Monivent Neo Training system, supplemented by verbal feedback from a trained facilitator.

Simulation Training

In October 2021, full-scale simulations were performed in accordance with recommendations from the INACSL with briefing, simulation, debriefing and evaluation (18). A trained simulation facilitator was responsible for all four phases of the simulation. The objectives and scenario were presented to the students prior to the simulation training. Each simulation session lasted approximately 75 min; 10 min were used to prepare and present the students to the manikin and simulation room, the simulation scenario lasted 20–25 min, followed by a 30–40 min debriefing. The resuscitation teams in the simulated scenarios consisted of three students ($n = 24$) and one physician. In each team, one student was assigned the main nurse role with responsibility for airway management. The other two students were handling medications, prepared equipment for intubation, etc. All teams simulated the scenario twice, with a change of tasks and roles between the two scenarios. The time schedule allowed for ten students to be randomly selected to take the main nurse role of managing the airways in a scenario. The premature manikin (Premature Anne, Laerdal Medical, Stavanger, Norway) was used and the same ventilation variables as in the second session of the skills training (premature manikin) were recorded with the Monivent Neo training system. However, the students did not receive feedback on the ventilation parameters.

Monivent Data Collection and Recording

Testing of the setup with support from Monivent AB revealed no internal air leak in the Premature Anne manikin airways. The target VT_e was 4–6 ml/kg and set according to a 750 g infant (Premature Anne, Laerdal Medical). A flow sensor (Neo Training, Monivent AB) was placed between the facemask (Monivent AB) and a self-inflating bag (Laerdal Silicone Resuscitator, Laerdal Medical) to measure and display on a tablet (iPad, Apple Inc., Cupertino, CA, United States), graphically and numerically mask leakage (%), expiratory tidal volume (VT_e in ml/kg), ventilation rate (min^{-1}) and inflation pressure (cm H_2O) in real-time. The tablet wirelessly stored the variables for later analysis.

Questionnaire 1

After skills- and simulation training had both been completed, a structured Likert-scale questionnaire was used to investigate the students' self-perceived competence in bag-mask ventilation before vs. after skills- and simulation training. In the questionnaire, the students also reported in which category NICU they were employed, whether they had performed neonatal ventilation in clinical practice, and the number of years of clinical work experience.

Questionnaire 2

To shed light on the results, a *post-hoc* questionnaire was distributed to investigate the students' preferred ventilation device, whether they were used to being in charge of airway management, and about their perceived stress in the simulation training.

Data Handling and Statistical Analyses

We tested for differences in the fraction of correct ventilations (VT_e) between sessions (skills- or simulation training) by making cross tabulations. To examine the direction of potential differences, we made box and whisker plots and bar charts. Continuous variables were compared between sessions with Mann-Whitney *U* non-parametric test. Categorical variables are presented as numbers with percent and continuous variables as median with interquartile range (IQR). *P*-values are 2-sided and significance level < 0.05. Statistical analyses were performed with IBM SPSS 27 for Mac (IBM Corporation, Armonk, NY, United States).

RESULTS

Data were registered from the 10 students who performed bag-mask ventilation both in the skills training and during simulation. These students had median (IQR) years of clinical experience of 7 (4–11) years, ranging from 3 to 16 years. One student worked in a category 3a NICU, two students in a category 3b NICU, and seven students in a category 3c NICU. Except for the student from the 3a NICU and one student from a 3c NICU, all students reported having performed neonatal ventilation in clinical practice. Eight students answered the *post-hoc* questionnaire 2. Five students preferred the T-piece, two preferred a bag, and one had no preferred device for manual ventilations. Three students were familiar with being responsible for airway management, whereas five students were not used to having this role. The simulation training was perceived as being stressful, but for most ($n = 6$), experienced as positive stress, e.g., helping them to stay focused.

Summary Results All Students Pooled

We analyzed 4.166 ventilations, 876 during skills training and 3.290 during simulation.

In the skills training, 52% of ventilations had a higher than recommended VT_e, and 18% lower than recommended. In the simulation training, 31% of ventilations had a higher than recommended VT_e, and 48% lower than recommended. The fraction of correct ventilations (30% versus 21%) was significantly different between skills and simulation training ($p < 0.001$).

Figure 1 presents ventilation parameters during skills- vs. simulation training. Leakage was 30 (8–48) and 70 (40–91)% ($p < 0.001$), respectively; VT_e was 6 (5–8) and 4 (2–7) ml/kg ($p < 0.001$), ventilation rate 32 (27–40) and 42 (33–53) min^{-1} ($p < 0.001$), and inflation pressure 20 (17–24) and 20 (15–25) cmH_2O ($p = 0.92$), respectively.

Individual Student Results

Figures 2, 3 present individual student results. One student (#4) had similar results for mask leak and ventilation rate during skills training and simulation. The other students had results consistent with the summary results, i.e., a higher leakage and ventilation rate, and lower VT_e in the simulation compared with skills training.

Questionnaires

The results of questionnaire 1 are presented in **Figure 4**. One student perceived his/her bag-mask ventilation and corrective action skills as being lower after skills- and simulation training but expressed that the lectures, skills training, and simulation contributed to an increased level of competence. In the remaining questionnaires, there was a slight improvement in how the students assessed their own skills in bag-mask ventilation and corrective actions, with more students rating their skills as "high" after skills- and simulation training. However, the difference was not significant ($p = 0.22$ and $p = 0.55$ for bag-mask ventilation skills and ventilation corrective actions, respectively).

DISCUSSION

In previous studies, results from real-time feedback have either been masked or made visible to the participants during ventilation (10, 14). In this study, the participants trained their ventilation skills with visible real-time feedback, followed by a simulation without visible feedback. The results showed that, almost uniformly, advanced clinical neonatal nursing students had a higher mask leak and ventilated at a higher rate during simulation compared to skills training. Despite a high mask leakage, median VT_e was within the recommended range both during skills- and simulation training. However, VT_e was highly variable with a high rate of both under- and over-inflation. The inflation pressure was quite consistent and within the recommended range in both the skills and simulation training.

Our results are in agreement with Gomo et al. (21) who found that mask leakage itself did not impair tidal volume delivery. We found a median mask leak of 30% with feedback and 70% without feedback, but a VT_e within the recommended range. Gomo et al. (21) speculated that the leak is not constant but dynamic, which suggests that some variation in leakage and VT_e can be tolerated. Notably, in our study, the fraction of correct VT_e's was very low both in the skills training and simulation.

Despite our students' *post-hoc*-reporting of "positive stress," a higher ventilation rate may reflect a negative stress-response during simulation. Resuscitation situations often cause stress among the involved staff (22), and to relieve the stress in such acute complex situations, theoretical knowledge and practical skills are important (8). Our students participated in lectures to provide them with theoretical knowledge, and practical skills training. Unfortunately, these learning activities did not result in the expected learning outcomes of high-quality ventilation in a simulated scenario.

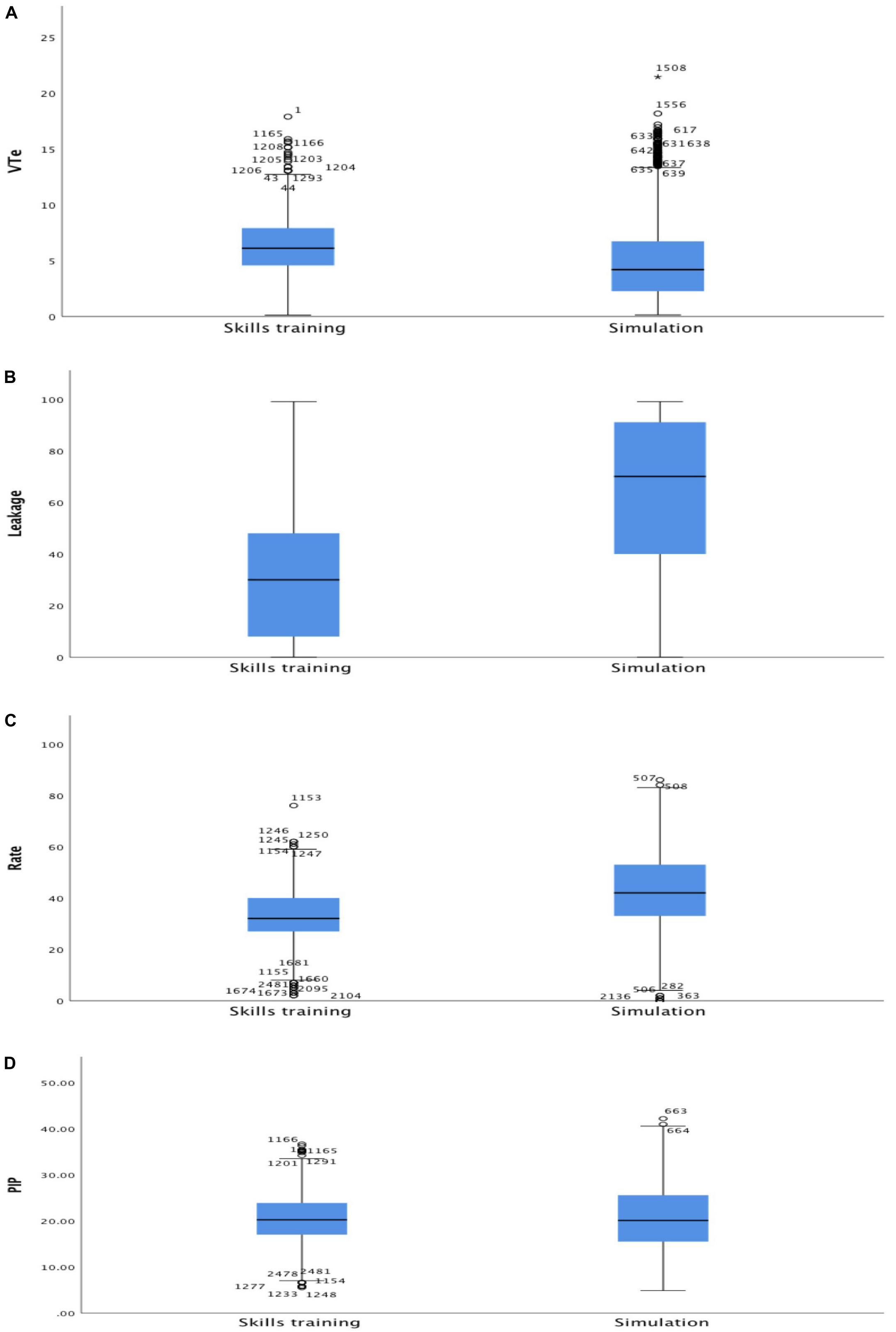

FIGURE 1 | Box plots all students combined of **(A)** expiratory tidal volume (VT_e, ml/kg), **(B)** leakage (%), **(C)** ventilation rate (min^{-1}), and **(D)** positive inspiratory pressure (PIP, cmH_2O) during skills and simulation training. Within each box, the horizontal black line represents the median value; boxes extend from the 25th to the 75th percentile; while the whiskers represent the minimum and maximum values, respectively.

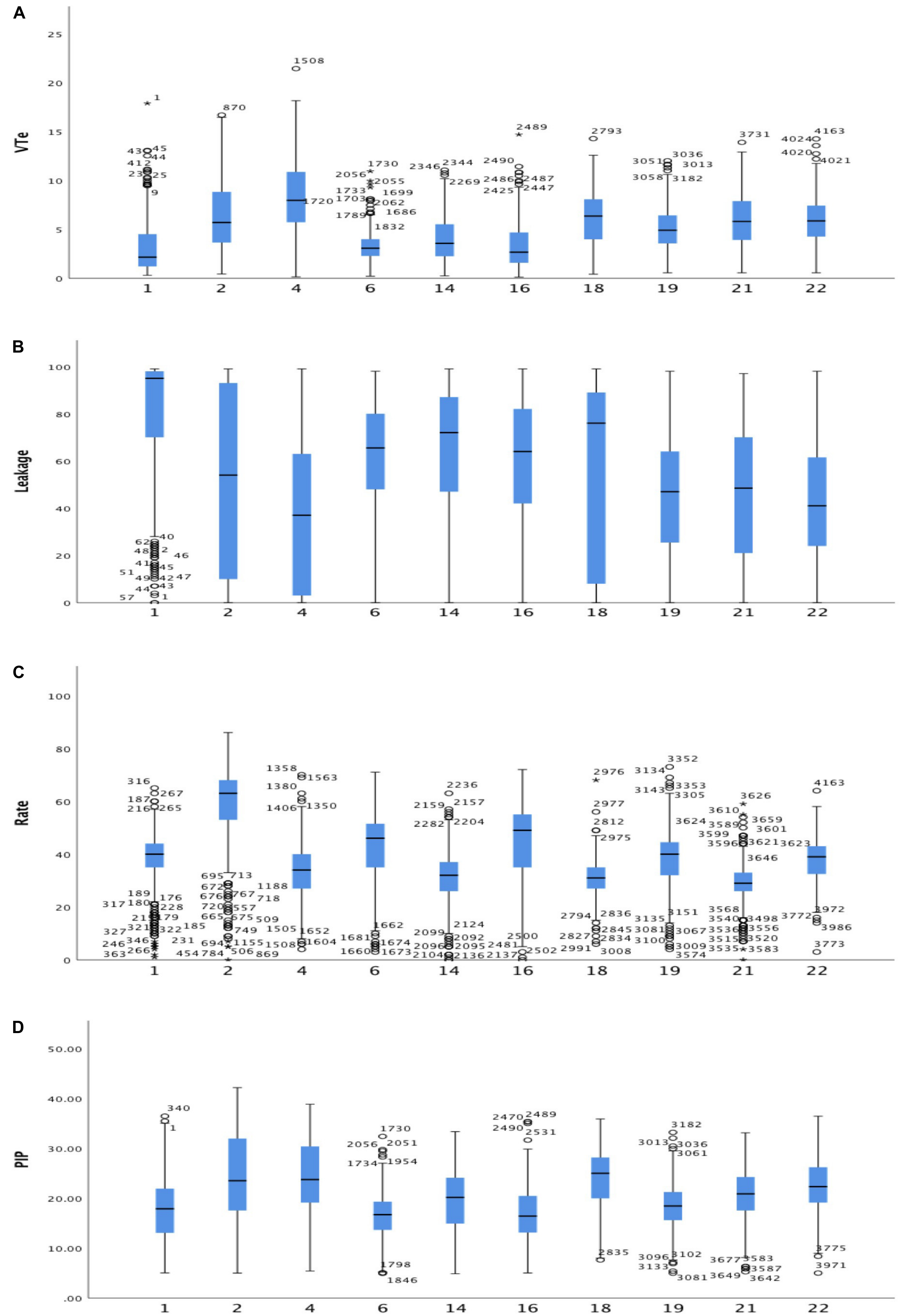

FIGURE 2 | Box plots individual students, skills training and simulation combined of **(A)** expiratory tidal volume (VT_e, ml/kg), **(B)** leakage (%), **(C)** ventilation rate (min^{-1}), and **(D)** positive inspiratory pressure (PIP, cmH_2O). Within each box, the horizontal black line represents the median value; boxes extend from the 25th to the 75th percentile; while the whiskers represent the minimum and maximum values, respectively.

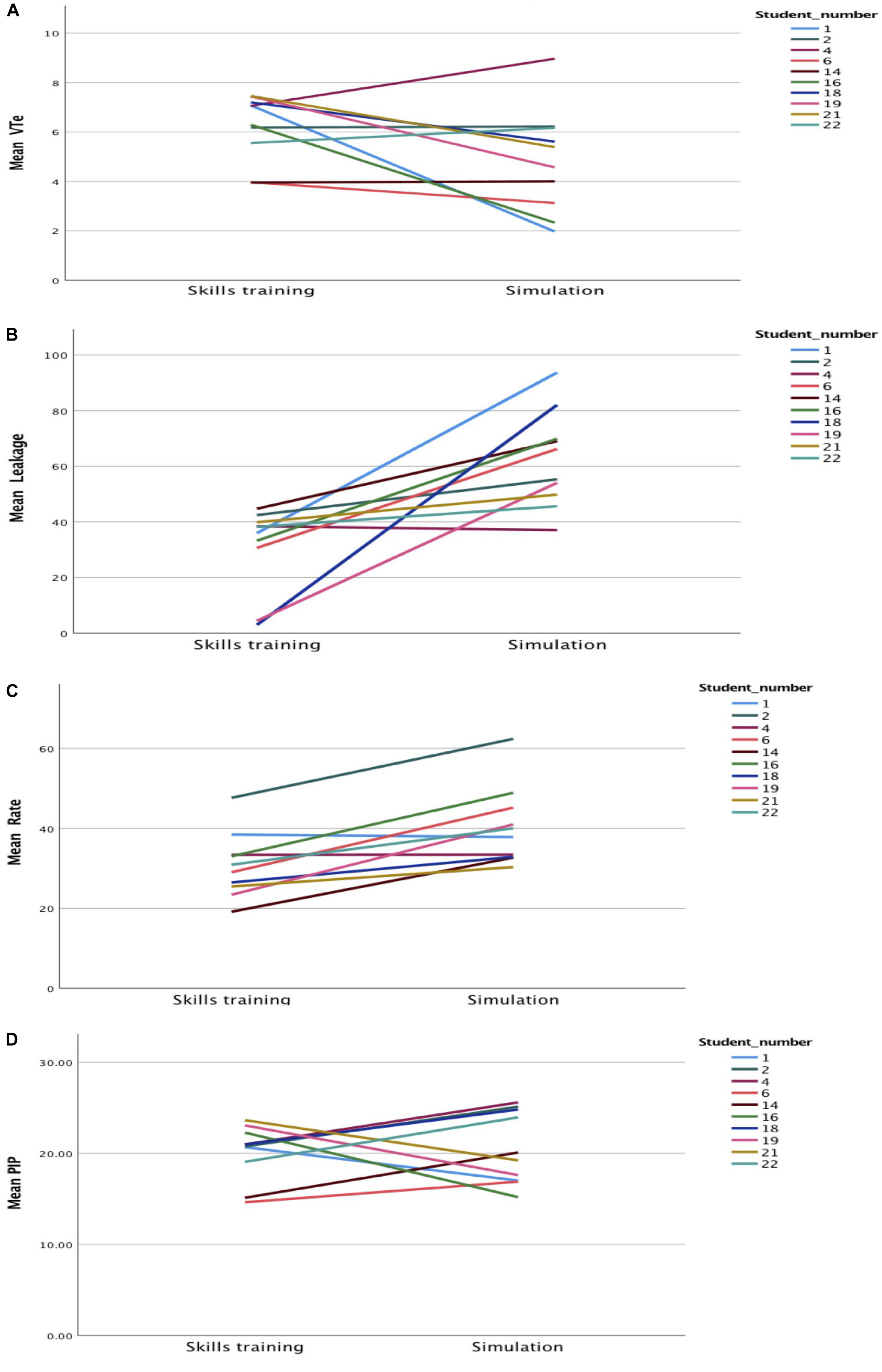

FIGURE 3 | Spaghetti plots individual students of **(A)** expiratory tidal volume (VT_e, ml/kg), **(B)** leakage (%), **(C)** ventilation rate (min^{-1}), and **(D)** positive inspiratory pressure (PIP, cmH_2O) during skills and simulation training.

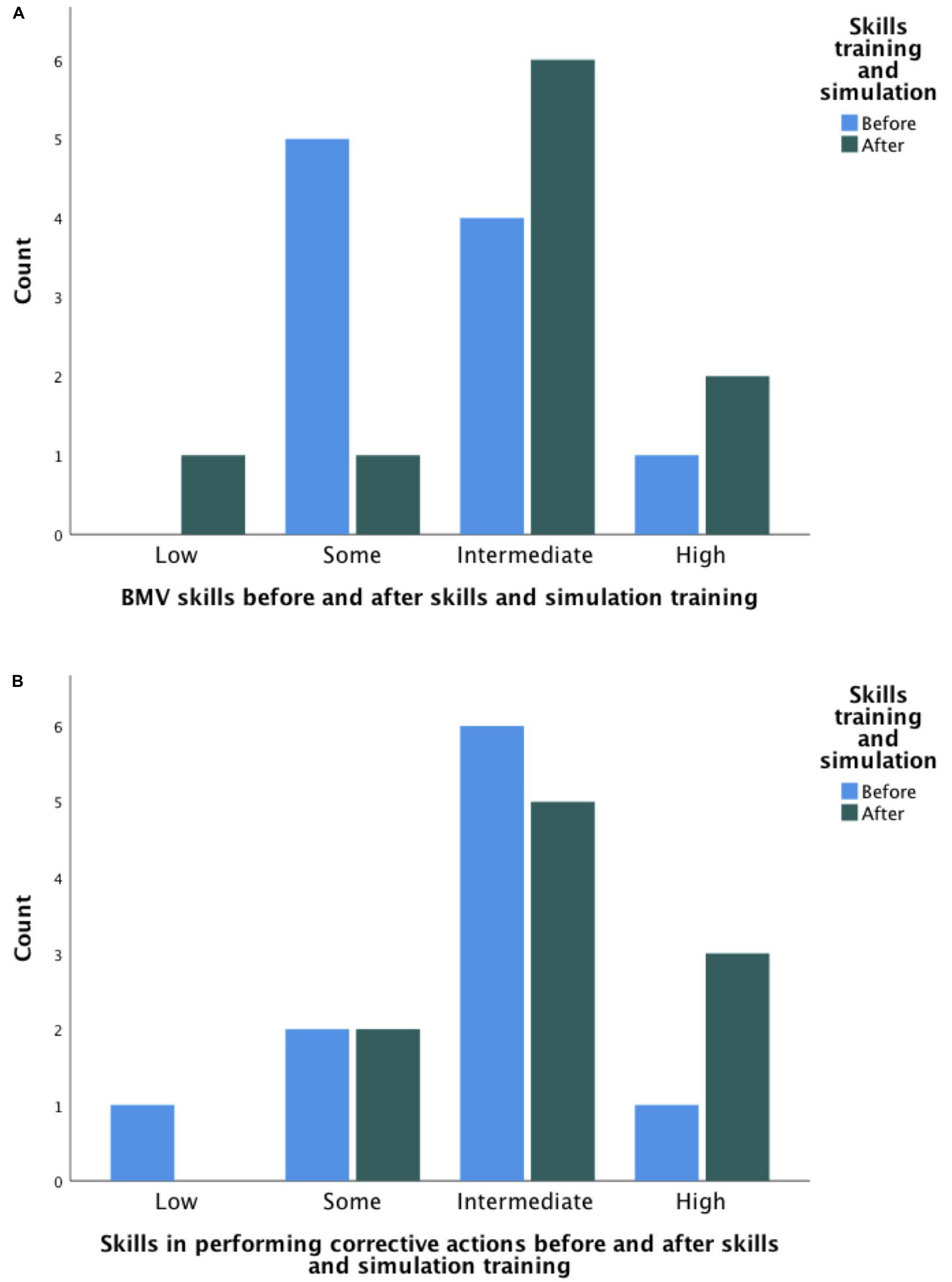

FIGURE 4 | Bar chart of students' self-assessed skills in **(A)** bag-mask ventilation (BMV) and **(B)** ventilation corrective actions before (blue) and after (green) skills and simulation training.

It is the responsibility of both the individual healthcare professional, educational institutions and the NICU leadership that knowledge of and skills in providing safe and effective ventilation are repeatedly trained and tested. The results from this study contrast with studies that found that training with real-time feedback improved ventilation performance (10, 14), and in the following we discuss potential causes for this discrepancy.

The Time Between Skills Training and Simulation

Anderson et al. (23) aimed to find the optimal frequency of resuscitation skills training for learning and retention, and found that the time between training sessions negatively correlated with nurses' cardiopulmonary resuscitation (CPR) performance. They concluded that brief, but frequent training on a manikin improved performance. The monthly frequency of training scored higher on performance than training every third, sixth, and twelfth month (23). Although the study investigated CPR skills on adult, not premature manikins, it is likely that the results are transferable since both adult and neonatal resuscitation skills need to be maintained to be used in similar stressful situations. This is further supported by van Vonderen et al. (24) who demonstrated that 2 min daily ventilation training improved NICU staff's ventilation skills. The study contended that a 2-min training session is manageable for any unit if it is planned and prioritized (24).

Clinical Experience and Role

Our participants were adult learners and had a median (IQR) year of clinical experience of 7 (4–11) years, but only 8 out of 10 reported to have performed neonatal ventilation in clinical practice. According to Mumma et al. (25), an *expert provider* has more than 8 years of professional experience from working in a critical environment, while a *novice* has no more than 2 years of professional experience. The student who had consistent results for mask leakage and ventilation rate during skills training and simulation had 5 years of clinical experience, no hands-on experience with clinical neonatal ventilation, and scored "to some extent" on self-perceived competence before skills- and simulation training. We may only speculate how this student managed to perform well in the simulation, e.g., by observing manikin chest rise and by utilizing the lessons learned from the skills training. Another explanation may be that this student has a higher appraisal of her stress-coping ability, and accordingly, lower perceived stress than the other students, this will be discussed later.

Except for the student from 3a NICU and one student from a 3c NICU, all students reported having performed neonatal ventilation in clinical practice. In clinical practice, nurses must be properly trained in the early identification of clinical deterioration (26) and must be prepared to initiate stabilizing measures including bag-mask ventilation as physicians are often not immediately available (27). Despite the students' experience from level 3 NICUs, it can still be assumed that this was an unfamiliar role for the students. The *post-hoc* questionnaire confirms our assumptions that the simulated scenario may have caused a different stress response in our nursing students than the pediatric trainees in the study by Lizotte et al. (22).

Stress and Non-technical Skills

Having an unfamiliar role in the simulated setting may contribute to participant stress. Lizotte et al. (22) found that resuscitation simulations caused both anticipatory and participatory stress in pediatric residents, measured by salivary cortisol (objective stress) and a questionnaire (subjective stress). Anticipatory stress is described as stress that occurs prior to a simulation. Participatory stress is the stress experienced during the simulation (22). Surprisingly, neither objective, nor subjective stress interfered with the participants' performance (22). If the result of that study is transferable to our participants, stress may not be the main reason for the suboptimal ventilation performance during the simulation.

All 10 students had the same lecture and skills training 8 weeks before the simulation, and all of them were experienced nurses working in relatively high-acuity level 3 NICUs. However, some individual differences will naturally appear in a group. These characteristics can be understood as non-technical skills and may have contributed to the differences in performance. The students in this study confirmed that simulation training is a stressful situation but stated that they became more focused on the tasks and managed to stay calm even though they were stressed. Non-technical skills include cognitive and social skills that complement technical skills (28), which can be attributed at the individual level to human factors (5, 6, 8). By practicing these skills in team situations, performance under stress may be improved (29).

Do We Need More Real-Time Feedback?

Eye-tracking was used to measure visual attention, and Monivent provided real-time feedback in a recent randomized simulation study (10). Without the feedback, participants used chest rise and watched the position of the facemask to assess the effectiveness of ventilation. Real-time feedback was superior to using clinical assessment (10). In our study, we wanted to find out if prior training with real-time feedback improved simulation performance without feedback. We found that mask leakage, VT_e, and ventilation rate were variable, perhaps because real-time feedback was not provided in the simulation. However, VT_e was often outside the recommended range, even with feedback. We speculate that students in the master's degree program may need time to grow accustomed to feedback-devices while learning how to use them properly. For future research, it would be interesting to study whether the results improve with more training with real-time feedback before simulation. It might also be interesting to study whether training both with and without real-time feedback before simulation, improves performance.

Strengths and Limitations

A strength of this study is that it contributes to filling a knowledge gap in our understanding of neonatal ventilation skills in nurses, as opposed to medical students and physicians. The study was a collaborative effort between the nursing and medical profession, and between higher education and clinical practice. Limitations include a low number of participants. Despite the low number of participants, the study indicates that human factors need more attention in the education of advanced clinical neonatal nurses. All the students had experience with simulation training in clinical practice before the start of the master's degree program, but it is a limitation that this study did not include a baseline simulation, the reason for which has been explained in the methods section. The equipment we used, i.e., the self-inflating bag and mask, may not have been the best when a T-piece is often the device used in the clinical field. In further studies, the participants should be allowed to choose the resuscitation device they are most familiar with. The manikin was checked for an internal air leak, but it is still possible that this may have occurred undergoing ventilations.

Despite these limitations, we believe that our study provides useful learning points for educational contexts and clinical practice.

CONCLUSION

For students in the master's degree program in advanced clinical neonatal nursing, skills training with real-time feedback on mask leakage, tidal volume, ventilation rate, and inflation pressure did not result in high-quality bag-mask ventilation in a stressful simulated scenario. The objective measures agreed with the students' own perceptions that their skills had not improved after the skills- and simulation training. In future studies, it would be of interest to try to distinguish individual differences influencing stress management in the performance of bag-mask ventilation in simulated neonatal resuscitation. It would also be interesting to investigate if more frequent training before simulation, and both blinded and visible real-time feedback training would improve the simulation results.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Norwegian Center for Research Data (NSD)–reference number 890517. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

IR performed the data collection. IR and AS conceptualized the study and analyzed and interpreted the data. IR and A-KJ drafted the initial version of the manuscript. HA and AR contributed to the conceptualizing, data analysis, and interpretation. All authors participated in critical revision of the manuscript for important intellectual content, approved the final manuscript as submitted, and agreed to be accountable for all aspects of the work.

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Targeted Training for Subspecialist Care in Children With Medical Complexity

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Background: Children with medical complexity (CMC) are prone to medical errors and longer hospital stays, while residents do not feel prepared to provide adequate medical care for this vulnerable population. No educational guidance for the training of future pediatric tertiary care specialists outside their field of expertise involving the multidisciplinary care of CMC exists. We investigated pediatric residents past educational needs and challenges to identify key learning content for future training involving care for CMC.

Methods: This was a prospective mixed-methods study at a single pediatric tertiary care center. Qualitative semi-structured interviews with residents were conducted, submitted to thematic content analysis, linked to the American Board of Pediatrics (ABP) general pediatrics content outline, and analyzed with importance performance analysis (IPA). Quantitative validation was focused on key themes of pediatric nephrology within the scope of an online survey among pediatric residents and specialists.

Results: A total of 16 interviews, median duration 69 min [interquartile range IQR 35], were conducted. The 280 listed themes of the ABP general pediatrics content outline were reduced to 165 themes, with 86% (theoretical) knowledge, 12% practical skills, and 2% soft skills. IPA identified 23 knowledge themes to be of high importance where improvement is necessary and deemed fruitful. Quantitative validation among 84 residents and specialists (response rate 55%) of key themes in nephrology yielded high agreement among specialists in pediatric nephrology but low interrater agreement among trainees and "trained" non-nephrologists. The occurrence of themes in the qualitative interviews and their calculated importance in the quantitative survey were highly correlated (tau = 0.57, $p = 0.001$). Two clusters of high importance for other pediatric specialties emerged together with a contextual cluster of frequent encounters in both in- and outpatient care.

Conclusion: Regarding patient safety, this study revealed the heterogeneous aspects and the importance of training future pediatric tertiary care specialists outside their field of expertise involving the multidisciplinary care of CMC. Our results may lay the groundwork for future detailed analysis and development of training boot camps that might be able to aid the improvement of patient safety by decreasing preventable harm by medical errors, especially for vulnerable patient groups, such as CMC in tertiary care pediatrics.

Keywords: nephrology, medical education, training, medical complexity, children with medical complexity (CMC), residency, patient safety, children with chronic disease

INTRODUCTION

Preventable harm in healthcare occurs in about 6% of patients across medical care settings (primary care, hospitals, intensive care units), with 12% leading to permanent disability or death (1). Medication and procedure-related errors, as well as nosocomial infections, are the most common adverse events in hospitals (2). Peaks of healthcare-related adverse events have been observed to reoccur annually during July and August in the United States and the United Kingdom, decreasing progressively after 1 month (3, 4). This tendency coincides with the enrolment of many new trainees and fellows at teaching hospitals, annually over 32,000 and 100,000 in Europe and the United States (5, 6). Such data suggest that current medical education does not sufficiently prepare graduates for their future work environment (3, 7–9).

Children with medical complexity (CMC) account for an increasing proportion of hospitalized pediatric patients resulting in about one-third of total pediatric healthcare costs (10–13). These patients are at particular risk for medical errors and longer hospital stays (14–18). Several studies suggest that residents often feel overwhelmed, anxious, and in doubt of their skills when caring for CMC (11, 19, 20). There is a high need for novel measures to equip pediatric residents with the knowledge and skill set to improve their performance in early clinical training, thus increasing patient safety (12).

Simulation-based boot camps at the beginning of clinical training might be an effective way to prepare young physicians for their future clinical environment (9, 21). A web-based multimedia curriculum for pediatric residents increased satisfaction, knowledge, behavior change related to verbal handoffs, and comfort with clinical care of CMC (18). This curriculum primarily focuses on the care of CMC with neurological impairment and technology dependence (e.g., spasticity, tracheostomy tubes).

In the care for CMC, important differences exist between Europe and the United States. In Europe, tertiary care center subspecialists care for all patients, including CMC. In contrast, in the United States, hospitalists mainly provide the care for these patients. Hospitalists are defined as "a physician whose primary professional focus is the general medical care of hospitalized patients and whose activities include patient care, teaching, research, and leadership related to hospital medicine" (22). Consequently, different needs and challenges for new residents becoming future pediatric subspecialists might prevail.

In the literature, several national educational curricula, syllabi, and content outlines for general pediatrics and pediatric subspecialties exist (23–28), in addition to individual efforts of needs assessments in particular areas of medicine for future general pediatricians, e.g., pediatric palliative care, pediatric gastroenterology curricula, or essential hypertension for primary care pediatricians (29–31). However, as Abbott and First concluded, a "one-size-fits-all" approach to pediatric residency training cannot be justified as training needs for subspecialty pediatricians and hospitalists primarily working in hospital-based medicine are sufficiently distinct from those of subspecialty pediatricians and general pediatricians working mainly in ambulatory medicine (32).

Currently, no national or international educational guidance for the training of future pediatric tertiary care specialists outside their field of expertise involving the multidisciplinary care of CMC exists. Some examples of similar schools of thought have been published in internal medicine (33–36), but to the best of our knowledge, no needs assessment for the training of residents becoming future subspecialists at a pediatric tertiary care center caring for CMC has been published yet. The primary objective of this mixed-methods study was to evaluate the pediatric resident's past educational needs and challenges during their clinical rotation in specific subspecialty areas of pediatrics (e.g., pediatric nephrology, pediatric cardiology) and to define key learning content for future resident and subspecialty training involving care for CMC.

METHODS

Setting

The Comprehensive Center for Pediatrics at the Medical University of Vienna is the largest Austrian academic tertiary care center that focuses almost exclusively on caring for children with severe or orphan acute and chronic diseases in both inpatient and outpatient medicine. The Austrian pediatric residency curriculum is set for 6 years. At our center, all residents need to accomplish their training at the same, a total of six, different specialized divisions ("rotations;"

pulmonology, allergology, and endocrinology; neurooncology and epileptology; cardiology and hemostaseology; nephrology, gastroenterology, and rheumatology; pediatric intensive care medicine and neonatology; pediatric ambulatory care) to learn the whole spectrum of pediatrics, with approximately 80% inpatient and 20% outpatient care.

A prospective mixed-methods study was conducted at the Department of Pediatrics and Adolescent Medicine. This study consisted of two phases, namely, (1) qualitative explorative interviews with a convenience sample of pediatric residents at different stages of clinical training to explore and evaluate educational needs and challenges yielding a defined set of competencies in the form of knowledge, practical skills, and soft skills in specific highly specialized work environments; and (2) quantitative validation (online survey) with all pediatric residents and specialists to rank these individual competencies through a larger-scale survey to create a more profound content outline. Approval was granted by our university's data protection agency beforehand.

Qualitative Explorative Interviews

Qualitative explorative interviews were conducted from November 2019 until February 2020 by two researchers (FE and AH), supervised by an expert in qualitative research (VR). At the time of screening (10/2019), 58 residents were potentially eligible for inclusion in phase I of this study. In detail, we conducted open-ended, semi-structured individual interviews to allow in-depth discussion in a private setting to talk about their perceived resources and demands (37). Our developed and piloted semi-structured interview guide is given in the **Supplementary Material**. The interviews were audio-recorded and transcribed verbatim. Analysis of the collected data was conducted utilizing a qualitative thematic content analysis to identify codes (37, 38). First, an initial code list was created by reading through the collected data. Codes are defined as words that act as labels for specific concepts and describe the meaning of a piece of text (38). For each coding unit, two different labels were assigned, namely, theme and group. Theme refers to the content of the coded segment, and group to the type of learning by context ("knowledge," "practical skill," "soft skill") and category refers to whether the theme of the coded unit was or was not learned by the resident during their rotation ("learned" vs. "missing," respectively), as seen in the context of the coded unit. Examples are given in **Table 1**.

To introduce better reproducibility and international standardization of our results, the original coded themes were linked to corresponding domains and subdomains as outlined in the American Board of Pediatrics (ABP) content outline created for the Pediatrics Board Examination in the United States. These content outlines drafted by content experts are regularly updated and available for different subspecialties, e.g., general pediatrics and pediatric nephrology (25–27). The content outlines are structured in a major content domain and several subdomains, e.g., content domain—*glomerular disorders*; subdomain—*nephropathies*; lower-order subdomain—*minimal change disease and variants* (27). We linked our previously identified themes to these content domains and subdomains.

TABLE 1 | Coding examples of the qualitative thematic content analysis.

Quote	Codes
"[…] on ward number seven, blood gas analysis was a major topic, as our attendings actively made sure, that we were learning this topic. Furthermore, during this time, nephrologists held lectures on this topic for us […]"	Theme = blood gas analysis Group = knowledge Category = learned
"[…] I would have hoped to get some critical care training early on, especially on how to sedate a child […]"	Theme = procedural sedation Group = practical skill Category = missing
"[…] as a chronically ill and multimorbid child was dying, which came to our ward specifically for palliative care, I did not know what to do […]"	Theme = end of life Group = soft skill Category = missing
"[…] and hemolytic uremic syndrome (HUS) is also a one of the classics, which is frequently seen on our nephrology ward, because HUS occurs every few months […]"	Theme = hemolytic uremic syndrome Group = knowledge Category = learned

In a few cases with added descriptors, the lowest appropriate content domain or subdomain was chosen to preserve the meaning of the themes in context with the interview's original quotes. This is a modified approach of the previously published rules for International Classification of Functioning, Disability and Health linking in qualitative research (39). Themes that fit into more than one subspecialty and themes where apparent linking was not possible were discussed between two researchers and a pediatrician and then consistently categorized. For example, the theme *hemolytic uremic syndrome (HUS)* (as given in **Table 1**) was linked to the lowest appropriate subdomain *thrombotic microangiopathies* within the ABP content outline, categorized within *pediatric nephrology* > *glomerular disorders* > *nephropathies with systemic disease* (27). To ensure validity of our qualitative data collection and analysis, the following strategies were embodied from the beginning until the completion of our study, namely, (1) audit trail to ensure optimal replicability (40), (2) peer review/debriefing with specialists from our department's education committee (41, 42), and (3) reflexivity of executive researchers (40, 43).

After initial analysis, we displayed the emerged themes according to Park's et al. model of the importance performance analysis (IPA, = needs assessment) (44), which aids to identify key themes of high importance with low performance, where focused improvement is needed and deemed to be fruitful (see **Figure 1**).

Quantitative Validation

To test the validity of this qualitative IPA, we set out to identify key themes within the IPA's results for focused interventions by a quantitative assessment. As pediatric nephrology was one of the three topics with the most identified themes of our IPA, we concentrated further investigations on this subspecialty: We submitted the 20 most frequently mentioned themes in pediatric nephrology to an online ranking among all physicians

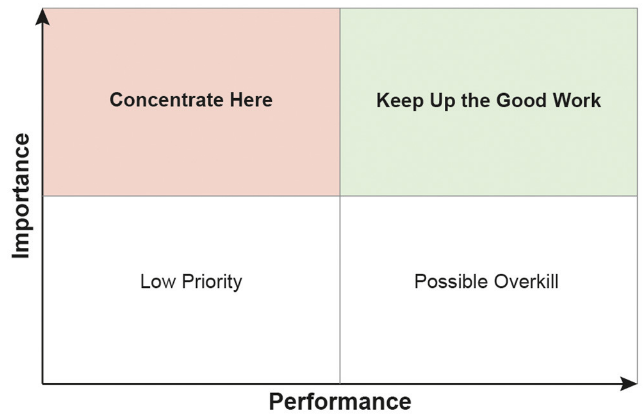

FIGURE 1 | Importance performance analysis (IPA = needs assessment) adapted from Park et al. (44). The importance of each theme is derived from the frequency (number of occurrences = in how many interviews it was coded), the performance by the categorization (learned vs. missing).

(= residents and specialists), utilizing SoSci Survey (SoSci Survey GmbH, Munich, Germany) (45). Each participant was asked to select the five top relevant ("TOP 5") and the five least relevant ("LEAST 5") themes (with the remaining 10 themes categorized as "Intermediate"). Participants were explicitly asked to assign the relative importance of each theme for training to become future tertiary care hospitalists outside pediatric nephrology. Furthermore, participants were asked to state their level of training (resident vs. specialist), and specialists were asked to declare their field of expertise. Survey invitations were emitted on March 1, 2021, and were online for 4 weeks. Participants received two reminders (after 1 and 3 weeks) to increase attendance.

Statistical Analysis

Descriptive data were analyzed using absolute and relative frequencies, median and interquartile range (IQR), or mean and standard deviation (SD) depending on data distribution. For each theme submitted to the survey, an importance score (IS) was calculated as the mean reciprocal rank, defined as the mean of 1 over the ranking assigned by each participant, in accordance with similar qualitative research in pediatric nephrology (46). For example, if a theme was ranked into the "TOP 5" category by one participant and in "LEAST 5" by another participant, the IS for this theme would be calculated as the mean of 1/1 and 1/3, resulting in an IS of 0.67, respectively. Differences of IS between groups were calculated by utilizing Student's *t*-test as IS represent mean reciprocal ranks. Kendall's *W* was calculated to assess interrater agreement among participants. Kendall's rank correlation was used to calculate correlation coefficients. All themes were submitted to cluster analysis by calculating Euclidean distances of IS across different groups of subspecialties and residents and submitting them to hierarchical Ward clustering. Subspecialties were analyzed when at least four specialists of the respective subspecialty participated in our survey or categorized in "other." Numbers of final clusters were evaluated based on contextual meaningfulness and discussed with experts in pediatric nephrology. Prioritization of themes and interrater agreement was further analyzed concerning experience, pooled by different training levels [Trainees (= residents), "trained" (= specialists outside pediatric nephrology), trainers [=specialists in pediatric nephrology)]. Statistical analysis was performed using IBM SPSS version 24.0.0.0 2016 (SPSS, Inc., Chicago, IL, USA) and R software (R Core Team 2020) (47).

RESULTS

Qualitative Explorative Interviews

Over 4 months, 16 interviews were conducted with 16 residents [10 women, median age 30 years (IQR4)]. Baseline characteristics of the total and the studied population were similar, with 38 and 31% of residents based on neonatology and pediatric intensive care units, and 62 and 69% based on general wards and intermediate care units, respectively. Furthermore, sex distribution among the targeted and studied population was comparable, with 63 and 64% female residents, respectively. With a median number of in-house ward rotations of 3 (IQR 3), our study population accurately represents an equally distributed spectrum of residents with a wide and heterogeneous clinical exposure on different stages of their education. This is being indicated by the range of interviewed residents from early training up to almost completion of residency with a median at "half-time" (= 3 rotations).

The median duration of individual interviews was 69 min (IQR 35 min). Participants mentioned a mean of 28 (SD ± 13) themes in their interviews. In total, 165 unique themes were identified, resulting in a mean of 10 (SD ± 7) unique themes per participant. In addition, 86% (141/165) of themes were assigned to (theoretical) knowledge, 12% (20/165) to practical skills, and 2% (4/165) to soft skills. Of these themes, 62% (122/197) were assigned as sufficiently trained (category: learned) and 38% (75/197) to need additional training (category: missing), with double mentions by different participants. Assignment to these groups did not differ between ages, numbers of in-house rotations, and sex. Categorization of emerged themes into various pediatric subspecialties is displayed in **Supplementary Table 1**.

Practical skills mentioned by at least four interviewees (25%) are displayed in **Table 2** and congregate into three distinct categories, namely, *resuscitation*, *sonography*, and *vascular/cerebrospinal fluid access*. Practical skills mentioned by <4 interviewees were *bladder catheterization* (19%, 3/16), *blood products transfusions* (19%, 3/16), *clinical presentation in neurology* (19%, 3/16), *incision and drainage* (19%, 3/16), and *transport management in critical care medicine* (13%, 2/16). Soft skills mentioned by at least two interviewees were *patient-parent-pediatrician relationship* (56%, 9/16) and *end-of-life care* (13%, 2/16).

The IPA of all emerged themes of our qualitative explorative interviews is displayed in **Supplementary Figure 2**. **Table 3** shows the extracted 23 (16%) key knowledge themes from 10 different pediatric subspecialties in the high-importance and low-performance panel, i.e., focused improvement is needed and deemed fruitful. In total, 20 themes of pediatric nephrology

TABLE 2 | Practical skills (mentioned by at least four interviewees) drafted from the qualitative explorative interviews ($n = 16$).

Practical skills	*N* (%)
Resuscitation	
Resuscitation	10 (63%)
Airway management	6 (38%)
Procedural sedation	5 (31%)
Stabilization and transition of newborn infants	5 (31%)
Sonography	
Point of care ultrasound (abdomen/emergency)	6 (38%)
Neuroimaging studies (sonography)	5 (31%)
Echocardiography (basic)	5 (31%)
Vascular/cerebrospinal fluid access	
Peripheral intravenous placement	16 (100%)
Central venous catheterization and handling	5 (31%)
Lumbar puncture	4 (25%)

TABLE 3 | Extracted key knowledge themes from the importance performance analysis (IPA) high-importance and low-performance panel ($n = 23$) ranked by their importance (= number of occurrence) with nephrology themes in bold.

Importance (ranked by number of occurrence)	Theme	Assigned subspecialty
5	General pediatrics	General pediatrics
5	Inborn errors of metabolism	General pediatrics
4	Intrathoracic respiratory infections	Pulmonology
3	**Sodium and water balance**	**Nephrology**
3	Normal growth and development	General pediatrics
3	Clinical dermatologic presentation	General pediatrics
3	Age-Appropriate medical screenings	General pediatrics
3	Handoffs across the continuum of care	Hospital medicine
3	Emergency conditions	Emergency medicine
3	**Hematuria and proteinuria**	**Nephrology**
2	Diarrhea	Gastroenterology
2	Seizures	Emergency medicine
2	Principles of chemotherapy	Hematology-oncology
2	Supraventricular arrhythmias	Cardiology
2	**Acid-base disorders**	**Nephrology**
2	Disorders of endocrinology	Endocrinology
2	Antimicrobial stewardship principles	Infectious diseases
2	Asthma	Pulmonology
2	Insulin deficiency with hyperglycemia	Endocrinology
2	Chronic diarrhea	Gastroenterology
2	Failure to thrive	Hospital medicine
2	**Urinary tract infection, bacteriuria, and pyuria**	**Nephrology**
2	Gastrointestinal bleeding	Gastroenterology

emerged during the qualitative explorative interviews (see **Supplementary Table 2**). In addition, 85% (17/20) of these themes were correctly identified by the IPA. Three themes (*urinary tract infection, bacteriuria, and pyuria*; *acid-base disorders; hematuria and proteinuria*) were correctly identified within the high-importance and low-performance panel, as occurrence of missing was higher than learned. Two themes (*core diagnostics in nephrology; chronic kidney disease and end-stage kidney disease*) that were 100% missing were not highlighted by the IPA as they were mentioned once only. The IPA also highlighted the theme of *sodium and water balance* although the majority declared it as learned (missing:learned = 3:6).

Quantitative Validation

Survey invitations were sent to all residents and specialists ($n = 154$). The response rate was 55% (84/154), with 14 being excluded due to doubled or incomplete entries, or due to ranking themes into "TOP 5" and "LEAST 5" categories simultaneously. A total of 70 responses (46%) could be included in our final analysis.

Of these, 46% (32/70) were residents and 54% (38/70) specialists, reflecting a mild overrepresentation of residents of the targeted medical staff (38% residents, 62% specialists). The remaining subspecialties were pooled and analyzed as a single category, namely, "other." The distribution of specialists among subspecialties within the targeted ($n = 84$) and the surveyed ($n = 38$) population were similar, with 32 and 34% from neonatology and pediatric critical care, 18 and 11% from pediatric cardiology, 10 and 11% from pediatric nephrology, 7 and 11% from pediatric pulmonology, and 33 and 34% from "other."

Figure 2 represents a significant high correlation between the occurrence of the theme in the qualitative interviews and the calculated IS with themes being assorted based on importance in the quantitative survey (tau = 0.57, $p = 0.001$). Themes of high importance in the qualitative interviews also display high importance within the quantitative survey. In contrast, themes that may be underrepresented in the interviews due to the lower number of participants show greater diversity along with the calculated ISs. Most importantly, *core diagnostics nephrology* and *chronic kidney disease and end-stage kidney disease* that the IPA, although classified as 100% "missing," failed to identify as important were assigned with higher IS within the quantitative validation.

Overall interrater agreement on IS was poor ($W = 0.3$, $p < 0.001$), as well as between residents ($W = 0.32$, $p < 0.001$) and "trained" ($W = 0.3$, $p < 0.001$). The highest interrater agreement was achieved between trainers ($W = 0.66$, $p < 0.001$).

Hierarchical clustering of the most frequently mentioned themes in pediatric nephrology by IS of trainees, "trained," and trainers resulted in three major contextual clusters, as displayed in **Figure 3**. Cluster number 1 representing the most important themes for future tertiary care hospitalists is *normal and abnormal blood pressure*, *electrolyte disorders*, *urinary tract*

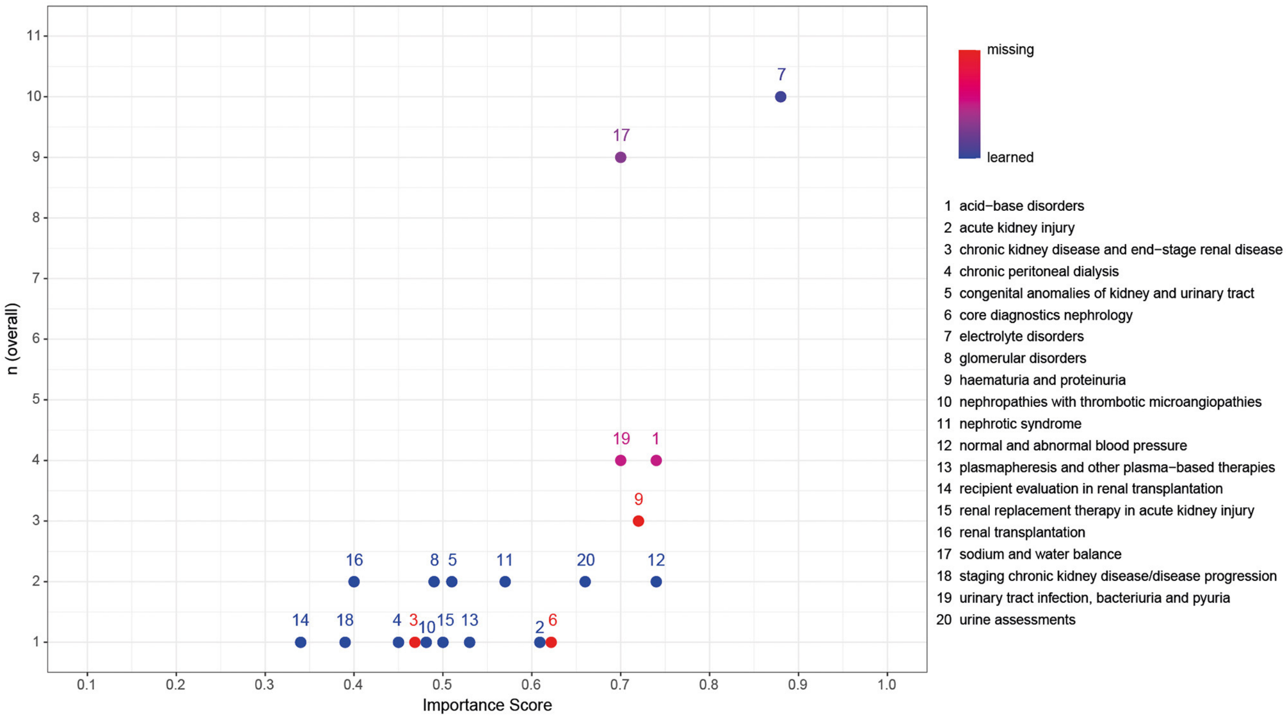

FIGURE 2 | Validation of the importance of key nephrology themes within the qualitative interviews with the calculated importance scores (IS) of the quantitative survey. Color coding represents classification as the ratio of missing:learned, with red representing 100% missing and blue representing 100% learned. Kendall's rank correlation tau = 0.57, $p = 0.001$.

infection, bacteriuria, and pyuria, *core diagnostics nephrology*, and *acute kidney injury*. Cluster number 2 represents a total of five further themes of high importance, resulting in a contextual cluster of frequent encounters in both inpatient and outpatient care (*urine assessments*, *nephrotic syndrome*, *hematuria and proteinuria*, *acid-base disorders*, and *sodium and water balance*). Together, clusters 1 and 2 cover both the themes identified by the IPA and one of the two themes not identified by the IPA, although classified as 100% "missing" (*core diagnostics nephrology*).

Although classified as 100% "missing" within the qualitative interviews, *chronic kidney disease and end-stage kidney disease* was not rated with high importance within the quantitative survey, neither by trainees, "trained," nor by trainers. Cluster number 3 represents themes where in-depth knowledge and specialization is needed and consists of themes related to end-stage kidney disease, renal replacement therapy, other extracorporeal treatments, and complex kidney diseases. In subanalysis, the theme *CAKUT (congenital anomalies of the kidney and urinary tract)* is rated with high importance by pediatric cardiologists and neonatologists/intensivists.

Representative quotes of the themes identified in both most important clusters (1 and 2) describing clinical situations where the importance of these themes was stated are given in **Supplementary Table 3**.

Supplementary Figure 3 represents the calculated IS for different training levels [Trainees (= residents), "trained" (= specialists outside pediatric nephrology), trainers (= specialists in pediatric nephrology)] themes being assorted on the basis of importance, with decreasing importance from left to right. Statistical comparison of IS is displayed in **Table 3**.

DISCUSSION

The aim of this explorative mixed-methods study was to evaluate educational needs and challenges faced by pediatric residents yielding competencies of knowledge, and practical and soft skills at an academic pediatric tertiary care center that focuses almost exclusively on caring for children with severe or orphan diseases. Several national curricula, outlines, and frameworks exist, defining the knowledge and skill set pediatricians should have acquired by the end of their residency or specialization training. However, the current literature does not offer consensus on specific training recommendations for interdisciplinary inpatient care for CMC with multiple-organ involvement (7, 14, 17, 18). Most importantly, a "one-size-fits-all" approach to pediatric residency training may not be appropriate as hospital-based pediatrics and pediatric primary care and ambulatory medicine are sufficiently different (32).

Our standardized qualitative analysis revealed the need for systematic incorporation of subject-specific clinical training in adjacent pediatric specialties for future highly specialized pediatric hospitalists caring for CMC with multiorgan disease. We reduced the 280 listed themes (= lowest domains) in the

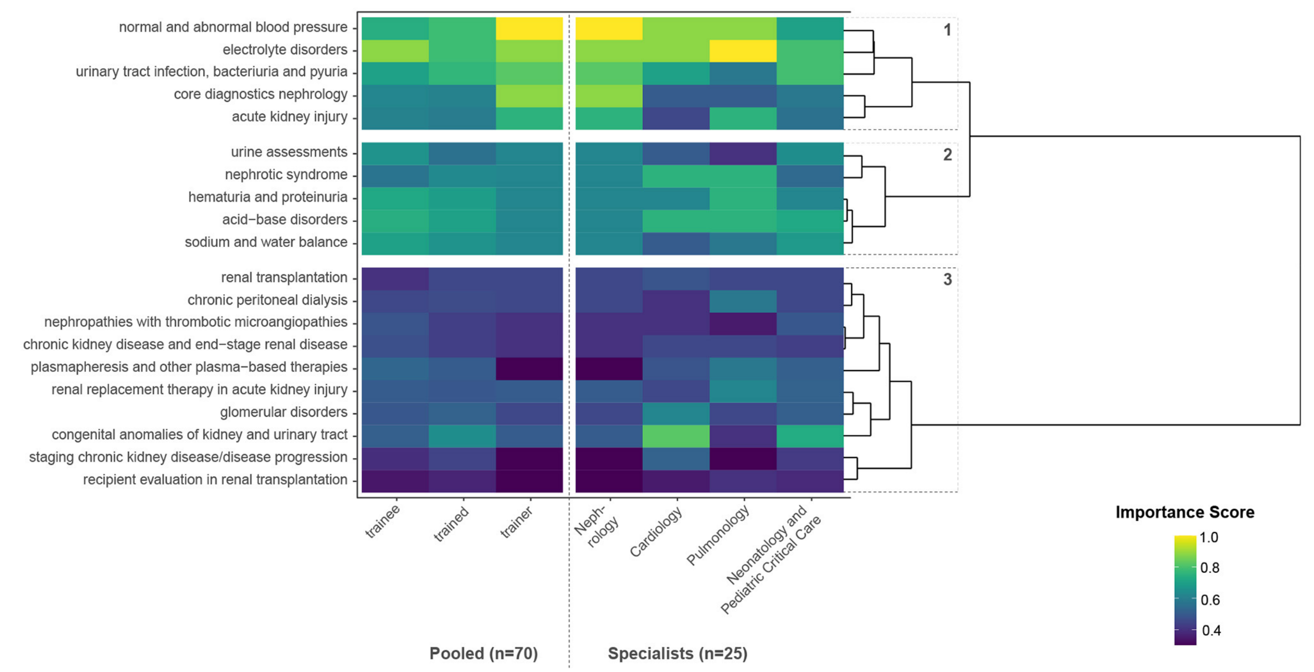

FIGURE 3 | Hierarchical clustering of the most frequently mentioned themes in pediatric nephrology by importance scores (IS) of trainees, "trained," and trainers, as well as different specialists.

ABP content outline to 165 unique themes and finally extracted 23 key themes where improvement is necessary and deemed fruitful. A subset of key themes in pediatric nephrology was validated by importance for training of future hospitalists in pediatric tertiary care. Hierarchical clustering of nephrology themes resulted in two clusters of high importance dominated by *normal and abnormal blood pressure*, *electrolyte disorders*, *urinary tract infection, bacteriuria, and pyuria*, *core diagnostics nephrology*, and *acute kidney injury*, together with a contextual cluster of frequent encounters in both inpatient and outpatient care (*urine assessments*, *nephrotic syndrome*, *hematuria and proteinuria*, *acid-base disorders*, and *sodium and water balance*). The third cluster, including e.g., renal replacement therapy, was rated as of low importance, most probably because these patients are usually consulted and very closely monitored by pediatric nephrologists.

In this study, we present the results and a methodological framework based on the educational needs in pediatric nephrology for tertiary care hospitalists in training as key learning content for the development of new curricula and/or further studies on this matter.

Heterogeneity of Medical Training Programs in Pediatrics

National educational content outlines are highly diverse and generally broad or specifically tailored to specialists needs. The Austrian training content outline for general pediatrics (48) consists of an obligatory basic training module and seven different additional modules (e.g., nephrology and urology; neuropediatrics, sleep medicine, psychosomatics), of which three must be chosen for in-depth clinical training. In contrast, the Royal College of Pediatrics and Child Health (RCPCH) general pediatrics syllabus for general pediatrics training in the United Kingdom (24) describes five general learning outcomes (e.g., resuscitation, team leading, and management) and a sixth learning outcome consisting of pediatric conditions from 14 areas of medicine. The US-focused ABP general pediatrics content outline (26) provides a more detailed description with 280 learning themes structured within 25 different content domains relating to several subspecialties of pediatric medicine.

Practical and Soft Skills

The identified practical and soft skill set (**Table 2**) generally matches the Austrian training content outline well, whereas the ABP and RCPCH only mention few practical and soft skills. Details are given in **Supplementary Table 4**. Despite being required, *quality improvement/assurance* did not occur in our analysis, which is in line with recent literature where only one-third of pediatric residents reported positive educational experiences in quality improvement (49). The importance of mastering skills such as *resuscitation* (63%) and *stabilization and transition of newborn infants* (31%) is reflected by a pediatric tertiary care survey where 72–96% of third-year residents attended events of cardiopulmonary resuscitation during their clinical practice (50). Another important skill set being mentioned by 19% of participants is *blood products transfusions*. As a recent international evaluation among pediatric residents concluded, there is an urgent need for improved education in transfusion medicine as this large international surveyed group of pediatric residents performed poorly on a transfusion medicine knowledge exam (51).

In our analysis, *patient-parent-pediatrician relationship* was considered a relevant soft skill to be mastered by medical trainees, which is also included in the Accreditation Council for Graduate Medical Education (ACGME) milestones to trace pediatric residents' development but does not specifically appear in the RCPCH or ABP content outline. Notably, *end-of-life care*, despite being mentioned only in 13% of our interviews, yielded strong emotional responses by the interviewed residents, particularly anxiety as no uniform training had been established: *"[...] Our daily hand-off for this patient was, that he was terminal and could die anytime soon. The first thing that came to my mind was, I hope this does not happen during my shift. At 5 a.m., 21 h into my shift, my only thought was: 3 h left until hand-off, thank God. My own mindset, that fact that I thought this way, is awful to me. Ideally, I should be able to say: okay, I am well-trained with this kind of situation, and I am able to care and provide support to the patient and his/her family. [...]"*. With more than 50% of deaths in childhood in the United States occurring in the hospital and only 39% of pediatric residents receiving adequate palliative care training (52), and as careful breakdown of our explorative qualitative analysis suggests, training in *end-of-life care* for pediatricians should be greatly enhanced. This has also been recommended by the American Academy of Pediatrics, the Institute of Medicine and the ACGME (52, 53). In line with other needs assessments specifically targeting pediatric palliative care, there is a clear need for increased efforts in pediatric palliative care education during residency training as residents perceived their training in palliative care to be inadequate with no improvement over time (30). Training future (pediatric) hospitalists in all of these skills is of great importance as some of these skills, e.g., blood products transfusions, are generally needed often and rarely produce adverse events, whereas others, e.g., *end-of-life care*, are needed rarely but have a high potential to go wrong.

Importance Performance Analysis: Knowledge

The 23 knowledge themes identified by our IPA with high importance and potential for improvement are generally well-represented in all three content outlines and might thus be regarded as extracted key themes for targeted training. Details of consistency and differences between content outlines and qualitative interviews are given in **Supplementary Table 5**. Noteworthy, the Austrian content outline includes additional aspects important for the care of CMC, e.g., *developmental and social pediatrics*, *psychosomatics*, *ergotherapy*, *analgesia*, *palliative care*, *follow-up care*, and *transition to adult care*, that were not identified by our IPA. In contrast, *antimicrobial stewardship principles* and *handoffs across the continuum of care* were identified with high importance and low performance by our IPA but are not mentioned in the analyzed national educational content outlines, although the ACGME milestones include handoffs as an important skill for residents. Especially *antimicrobial stewardship principles* is of valuable interest to hospitalists caring of CMC as the prevalence of multidrug-resistant bacterial infections in children has significantly increased during the last two decades (54). CMC may receive many antibiotic treatments during their lifetime, and studies have shown that antimicrobial stewardship programs can be effectively applied in pediatric inpatient settings, e.g., neonatal care (55). Medical errors are estimated to be attributed in approximately 80% to communication breakdowns. In particular for CMC, standardized high-quality *handoffs across the continuum of care* are essential for patient safety. However, as the committee on hospital care of the AAP states, "Hand-off communication is a skill requiring training and practice. Attending physicians are likely to benefit from ongoing training and monitoring of a standard approach to hand-offs" (56). This verifies our findings and highlights the importance of placing great emphasis on teaching *antimicrobial stewardship principles* and *handoffs across the continuum of care* to future hospitalists in pediatric tertiary care.

Themes in pediatric nephrology labeled with high importance (clusters 1 and 2 of **Figure 3**) in our analysis are generally well-covered by the RCPCH and ABP content outlines. In the Austrian general pediatrics content outline, no consistent standard exists on specific nephrology training for general pediatricians, let alone hospitalists/specialists outside pediatric nephrology. Therefore, to assume that future non-nephrology specialists, especially at tertiary care centers caring for CMC, should get by with the nephrological knowledge of general pediatricians is utopian fallacy. Our results indicate high importance of training in diagnostic tools essential to nephrology as the themes *core diagnostics in nephrology* and *urine assessments* emerged in a high-importance cluster in addition to *hematuria and proteinuria*, whereas the RCPCH syllabus and ABP content outline cast no additional focus on diagnostics. However, the ABP content outline explicitly features *genetic disorders, diseases, and conditions* in pediatric nephrology, which did not emerge in our analysis. Arguably there has been tremendous progress in the knowledge on genetic backgrounds of kidney disease, also dramatically influencing diagnostic progress and therapeutic pathways, e.g., for patients suffering from steroid-resistant nephrotic syndrome with genetic origins (57). This is of special importance since, on the one hand, communicative skills in the setting of *patient-parent-pediatrician relationships* emerged as highly relevant soft skill for young residents, but, on the other hand, literature reviews conclude that especially to young pediatric residents communication of complex medical information, especially genetic information, can be very challenging, and education of pediatric residents in these skills should be reinforced (58).

Quantitative Validation

The quantitative survey-based validation of key themes in pediatric nephrology of a subset of 20 identified nephrology themes revealed significantly high correlation (tau = 0.57, p = 0.001, as displayed in **Figure 2**). Themes of low importance display greater diversity along the calculated IS and may be underrepresented in the interviews due to a lower number

TABLE 4 | Comparison of importance scores (IS) between trainees, "trained," and trainers.

Theme*a	Trainees, IS ± SD	"Trained," IS ± SD	*p*-value*b	Trainers, IS ± SD	*p*-value*c
Electrolyte disorders	0.88 ± 0.22	0.78 ± 0.27	0.1	0.88 ± 0.25	0.95
Normal and abnormal blood pressure	0.74 ± 0.29	0.78 ± 0.28	0.61	**1.0 ± 0**	**<0.001**
Urine assessments	0.66 ± 0.28	0.56 ± 0.21	0.14	0.62 ± 0.25	0.83
Nephrotic syndrome	0.57 ± 0.2	0.63 ± 0.22	0.2	0.62 ± 0.25	0.67
Congenital anomalies of kidney and urinary tract	0.51 ± 0.21	0.64 ± 0.28	0.05	0.5 ± 0	0.73
Plasmapheresis and other plasma-based therapies	0.53 ± 0.22	0.5 ± 0.27	0.61	**0.3 ± 0**	**<0.001**
Renal replacement therapy in acute kidney injury	0.5 ± 0.21	0.49 ± 0.21	0.91	0.5 ± 0	0.08
Staging chronic kidney disease/ progression	0.39 ± 0.15	0.44 ± 0.2	0.28	**0.3 ± 0**	**0.002**
Recipient evaluation in kidney transplantation	0.34 ± 0.8	0.37 ± 0.14	0.4	**0.3 ± 0**	**0.006**

**aAll themes with a $p < 0.2$ are shown, themes with a $p < 0.05$ are given in bold; *bStudent's t-test between trainees and "trained"; *cStudent's t-test between trainees and trainers; p-values are unadjusted.*

of participants and free exploration of themes. Both themes classified as 100% "missing" and failed to be identified by the IPA received higher IS within the quantitative validation. This might reflect the implicit knowledge on diagnostic tools summarized in *core diagnostics nephrology* as well as for the care of children with *chronic kidney disease and end-stage kidney disease*. Themes of undoubtedly high importance, also after validation, were *sodium and water balance*, *electrolyte disorders,* and *acid-base disorders*, being an integral part of inpatient care.

As displayed in **Figure 3**, **Supplementary Figure 3**, and **Table 4**, perception of importance of themes between trainees, "trained," and trainers was similar but not identical, likely reflecting distinct training needs for different subspecialties. Only the theme *normal and abnormal blood pressure* was ranked higher by trainers than by trainees, whereas other significant themes (*plasmapheresis and other plasma-based therapies, staging chronic kidney disease/progression*) were ranked lower by trainers, which might stem from the trainers' point of view of consultant requests in these areas. This comes with no surprise as similar needs assessments between pediatric residents and attending staff for education in clinical pharmacology also resulted in similar but not identical learning needs (59). Accordingly, interrater agreement of relevancy was high between pediatric nephrologists (= trainers) but low among trainees and "trained" (= i.e., non-nephrology specialists). This corroborates different emphasis of nephrological themes in diverse subspecialties of pediatrics as, for example, the importance of *core diagnostics in nephrology* is perceived significantly different among specialists of neonatology and pediatric critical care vs. pediatric nephrologists. However, as displayed in Figure 4 homogeneous importance of major thematic clusters of nephrological themes for non-nephrologists could be identified despite minor differences between specialties.

Although the RCPCH syllabus includes *acute nephritis*, *chronic kidney disease,* and *enuresis* in their content outline, both *acute nephritis* and *chronic kidney disease* did not receive high ISs by non-nephrologists. This might stem from major involvement of pediatric nephrologists with these patients in the training environment of our tertiary care center since they represent a preselection of the most severe and complex cases. *Enuresis* did never emerge during our analysis as it being a generally common typical outpatient problem (60). *CAKUT*, being by far the major cause of chronic kidney disease (CKD) in childhood (48% of CKD), emerged as a topic of high importance to future non-nephrologist tertiary care specialists, especially for pediatric cardiologists (IS 0.8). These findings are not surprising given the association of *CAKUT* with congenital heart disease, e.g., DiGeorge syndrome (61). Given the high importance of *CAKUT* in multidisciplinary care, it seems surprising that this disease spectrum did not gain additional attention in the RCPCH syllabus.

Strengths and Limitations

To the best of our knowledge, this is the first study evaluating this special niche of residency training with "needs assessment" based on qualitative interview exploration, refined by quantitative importance validation. While several national and international educational frameworks and guidelines for pediatrics and pediatric subspecialties exist, they do not focus on the multidisciplinary treatment of CMC with multiorgan diseases involving collaboration among subspecialties. Several examples underlining the importance of interdisciplinary exchange in highly specialized areas of medicine can be drawn from literature in internal medicine, e.g., dialysis for non-nephrologists (33, 34, 36), CKD for non-nephrologists (35), or heart- and lung transplantation with associated renal complications (62). In addition, renal involvement in mitochondrial cytopathies (63) and cross-over areas such as pediatric onconephrology (64) might warrant relevant benefits for nephrological knowledge in other highly specialized areas of pediatrics. As this study was initiated by members of the pediatric nephrology team, we decided to focus on this subspecialty for validation, although themes from cardiology and general pediatrics were more frequently mentioned. Qualitative research explores the unexpected in specific populations by holistically seeking to understand the participants' perspectives on the phenomena of interest and might be more feasible than standard methods of quantitative research when evaluating processes and outcomes of medical education (38, 65). Due to the COVID-19 pandemic, we were compelled to abort qualitative interviews after 4 months. Regarding this shortcoming, some residents were deprived to mention important aspects, highly relevant to them, and rare themes might not have been emerged and identified by our analytic approach. Despite a limited number of qualitative interviews, interviewed residents are generally representative for target population in terms of baseline characteristics. Small participant numbers in each subcategory (i.e., nephrologists, cardiologists) limit accuracy of comparison for drawn conclusions on the basis of our survey. However, our analysis is strengthened by a survey with high interrater agreement between specialists of the thematic focus of this work.

CONCLUSION

This applied a mixed-methods approach to build key learning content for training needs of future subspecialty hospitalists caring for CMC, highlighting aspects of nephrology validated by an orthogonal method. A total of 280 listed themes within the ABP content outline were condensed to 23 key themes of high importance in need for improvement by an IPA, as well as to key themes in pediatric nephrology validated in a larger cohort for importance for training of future pediatric tertiary care hospitalists. Most importantly, future training should emphasize important aspects of patient safety beyond subspecialty training, such as *antimicrobial stewardship principles* and *handoffs across the continuum of care*, practical skills, such as *point-of-care sonography* and *blood products transfusions*, as well as *end-of-life care*. This study also introduces hierarchical clustering analysis to further tailor educational contents for a given subspecialty to distinct needs of pediatricians in training for another subspecialty. The knowledge basis and used methodologies of this study may lay the groundwork for future detailed analysis and the development of digital boot camps and might be able to aid the improvement of patient safety by decreasing preventable harm by medical errors, especially for vulnerable patient groups, such as CMC in tertiary care pediatrics.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

FE, CA, and MB developed concept and design, had full access to all the data in the study, take responsibility for the integrity and accuracy of the data and subsequent analysis, drafted the initial manuscript, conducted analysis and interpretation of data, and reviewed and revised the manuscript. IV, RS, AH, VR, and SB conducted further data analysis and interpretation. FE, AH, VR, IV, and RS collected all data presented in this manuscript. LK, LD-F, TS, KO, and ES performed critical revision for the manuscript for important intellectual content. All authors approved the final manuscript as submitted.

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SUPPLEMENTARY MATERIAL

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Provider Visual Attention Correlates With the Quality of Pediatric Resuscitation: An Observational Eye-Tracking Study

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Background: Eye-tracking devices are an innovative tool to understand providers' attention during stressful medical tasks. The knowledge about what gaze behaviors improve (or harm) the quality of clinical care can substantially improve medical training. The aim of this study is to identify gaze behaviors that are related to the quality of pediatric resuscitation.

Methods: Forty students and healthcare providers performed a simulated pediatric life support scenario, consisting of a chest compression task and a ventilation task, while wearing eye-tracking glasses. Skill Reporter software measured chest compression (CC) quality and Neo Training software measured ventilation quality. Main eye-tracking parameters were ratio [the number of participants who attended a certain area of interest (AOI)], dwell time (total amount of time a participant attended an AOI), the number of revisits (how often a participant returned his gaze to an AOI), and the number of transitions between AOIs.

Results: The most salient AOIs were infant chest and ventilation mask (ratio = 100%). During CC task, 41% of participants also focused on ventilation bag and 59% on study nurse. During ventilation task, the ratio was 61% for ventilation bag and 36% for study nurse. Percentage of correct CC rate was positively correlated with dwell time on infant chest ($p = 0.044$), while the overall CC quality was negatively correlated with dwelling outside of pre-defined task-relevant AOIs ($p = 0.018$). Furthermore, more dwell time on infant chest predicted lower leakage ($p = 0.042$). The number of transitions between

AOIs was unrelated to CC parameters, but correlated negatively with mask leak during ventilations ($p = 0.014$). Participants with high leakage shifted their gaze more often between ventilation bag, ventilation mask, and task-irrelevant environment.

Conclusion: Infant chest and ventilation mask are the most salient AOIs in pediatric basic life support. Especially the infant chest AOI gives beneficial information for the resuscitation provider. In contrast, attention to task-irrelevant environment and frequent gaze shifts seem to harm the quality of care.

Keywords: resuscitation, basic life support (BLS), attention, gaze, eye-tracking (ET), performance, simulation

INTRODUCTION

Pediatric cardiac arrest is a rare yet highly stressful event (1, 2). Resuscitation providers must work under high cognitive load and time pressure, which often leads to errors and deviations from proper protocol (3). To address this issue, simulation-based programs have been tested and recommended for medical education (4, 5). These programs effectively improved resuscitators' technical skills, but deficiencies in attentional and communication skills remained common and responsible for the majority of fatal errors and poor patient outcomes (6, 7). Consequently, it is imperative that healthcare providers (HCPs) are not only experienced in emergency procedures, but are also able to stay focused and work efficiently under pressure.

This study addresses attentional mechanisms related to the quality of resuscitation. Psychological research has shown that pressure causes attention to shift from task-relevant to irrelevant cues, which may result in disregarding important information and impaired performance (8). Yet the performance-harming effect of pressure is not inevitable; performers who have incorporated task-relevant cues into their execution routines perform better under pressure (9). Consequently, the knowledge about what are the most important task-relevant cues (and gaze behaviors) in pediatric resuscitation may substantially improve medical education and in turn the quality of clinical care.

Eye-tracking devices are an innovative tool to understand HCPs' attention during stressful medical tasks (10). Evidence on visual attention during neonatal and pediatric resuscitation shows that resuscitators mostly focus on the infant, displays, and airway equipment (11–15). Experts pay more attention to the patient's chest and airway than non-experts (16). These results imply that focusing on the patient and airway equipment are the most important gaze behaviors in pediatric resuscitation. However, evidence whether or not these gaze behaviors directly predict the quality of care is still missing from the literature.

The aim of this study is to identify HCPs' gaze behaviors that are related to the quality of pediatric resuscitation. This may help to advance medical training and propose relevant educational procedures. Based on the above findings, the infant and airway equipment represent the most salient cues or areas of interests (AOIs) in pediatric resuscitation. We thus hypothesize that the infant and airway equipment AOIs will be fixated by our participants and revisited more often than any other AOIs in a simulated resuscitation scenario. We further hypothesize that dwelling and refocusing on the infant and airway equipment AOIs is positively related to the quality of care.

MATERIALS AND METHODS

Participants and Study Design

This study was a secondary quantitative analysis of a randomized cross-over simulation study carried out in 2020, which examined the effect of feedback devices on visual attention and the quality of pediatric resuscitation (17). Originally, participants completed two pairs of scenarios: a chest compression (CC) scenario with and without a visible feedback device, followed by a ventilation scenario again with and without feedback. The feedback device was either visible or hidden from the participant, but always recording. It is important to note that we only included the conditions without any visible feedback device in this secondary analysis. This was because we did not want to bias the effect of gaze behavior on the quality of resuscitation by having an onsite feedback device. The presence of the feedback device caused participants to shift their attention to that device to a large extent, thereby substantially reducing attention to other stimuli (17). Consequently, the actual effect of gaze behavior on the quality of resuscitation could only be analyzed in the conditions without the feedback device. The present secondary analysis had an observational study character.

The original study was conducted at the Pediatric Simulation Training Center at the Medical University of Vienna, Austria. The study protocol was reviewed according to the Consolidated Standards of Reporting Trials approach, with the extension for simulation-based research (18). The Ethics Committee of the Medical University of Vienna gave this study an exempt status. Participants were medical students in their final year, fellows, nurses, and consultants from the Division of Neonatology, Pediatric Intensive Care and Neuropediatrics. Inclusion criteria were: medical students or HCPs affiliated with the Medical University of Vienna; available for 30 min; and provision of informed consent. Exclusion criterium was participation in previous eye-tracking simulation studies at our Simulation Training Center. All participants signed informed consent prior to participation and were then randomly assigned to perform CC twice (with and without feedback), and ventilations twice afterward. Hence, each participant completed a total of four basic life support (BLS) scenarios according to the European

Resuscitation Council (ERC) pediatric BLS guidelines (15:2) in a cross-over setting (19). The visibility of the feedback device was randomized (sealed envelope) within each pair of scenarios. Participants were wearing head-mounted eye-tracking glasses (Tobii Pro 2.0; Tobii AB, Danderyd, Sweden) to record their gaze behavior during all scenarios.

Study Procedure, Equipment, and Parameters

At the start of the study, participants were briefed on the study, received a brief review of the current pediatric resuscitation guidelines, and completed a questionnaire on demographic data and expertise in pediatric resuscitation. Thereafter, the eye-tracking glasses were calibrated according to the company's instructions by fixating a standardized calibration card with a black circle and a black dot in the middle at a distance of one meter. Calibration was performed before each scenario and had to be approved by the recording software before measurement. Participants then completed the four BLS scenarios. The resuscitation team consisted of the participant and a study nurse. Each scenario lasted for 3 min and all tasks were done in one session.

The QCPR Baby manikin (Laerdal Medical, Stavanger, Norway) was used in the CC scenarios, whereas the SimNewB manikin (Laerdal Medical, Stavanger, Norway) was used in the ventilation scenarios because it has no internal air leak. For the quality of CCs, the QCPR Baby was connected to the SimPad Plus Skill Reporter software (Laerdal, Stavanger, Norway) which recorded CC rate, CC rate compliance (percentage of correct CC rate), depth, depth compliance (percentage of correct CC depth), complete release, and hand position. In addition, the total compression quality score (%), which is the composite score of the above parameters, was calculated and provided by the software. Participants received 100% if the guideline criteria for each variable (CC rate of 100–120 CCs per minute; depth of 4 cm; complete chest recoil between each CC; optimal hand position) were executed accurately (19). For the quality of ventilations, a flow sensor (Neo Training, Monivent AB, Gothenburg, Sweden) was placed between the face mask (CareFusion Vital Signs Infant Face Mask, Châteaubriant, France) and the bag (Laerdal Silicone Resuscitator Pediatric Basic, Stavanger, Norway) to measure inspiratory (V_{Ti}) and expiratory tidal volume (V_{Te}), peak inspiratory pressure, and mask leak. Inspiratory pressure of <30 cmH_2O, tidal volumes between 4–8 mL/kg, and low leakage (as low as possible) reflect high quality of ventilation (1).

The eye-tracking glasses recorded a first-person view video with an overlying pupil fixation showing where participants were looking in real time (**Figure 1**). Eye movements were sampled at a rate of 50 Hz and analyzed with the Tobii Pro Glasses Analyzer software (Tobii AB, Danderyd, Sweden). Clinical experts of the research team determined six areas of interest (AOIs) before the study: (1) feedback device (if available), (2) infant chest, (3) ventilation mask, (4) ventilation bag, (5) study nurse, and (6) others (i.e., focusing outside of the predefined AOIs). Because we only analyzed CC and ventilation scenarios without a visible feedback device in this secondary analysis, the feedback device AOI was not relevant. The analyzed eye-tracking parameters were ratio (the proportion of participants who fixated a particular AOI), dwell time (total amount of time a participant attended an AOI), the number of revisits (how often a participant returned his gaze to an AOI), and the number of transitions between AOIs. Higher ratio and higher number of revisits both reflect the relative importance of an AOI, longer dwell time on an AOI represents conscious attention paid to that AOI, while high number of transitions between AOIs indicates insecurity or (inefficient) search in multiple information sources (20).

Statistical Analysis

Descriptive statistics were used to describe the sample and the ratio of each AOI. Repeated measures analysis of variance (ANOVA) with Bonferroni corrected *post hoc* comparisons were used to test the differences in revisits among the AOIs. Partial correlations were used to depict the relationship between visual attention, chest compression, and ventilation parameters, with controlling for the order effect (no-feedback condition first vs. second). Recall that, in the original study, participants performed both CC and ventilation tasks twice (with and without the feedback device), while being randomized whether they start with the feedback or the non-feedback condition. Participants who started with the feedback condition performed in the subsequent non-feedback condition significantly better than participants who directly started with the non-feedback condition ($p < 0.05$). Because only the non-feedback condition was analyzed in this study, we included the order of the non-feedback condition as a covariate in the above analyses. All above analyses were performed with SPSS 27.0 (IBM Corp., Armonk, NY, United States). The level of significance was set at $p < 0.05$ (two-tailed). Parameters with a skewed data distribution were log transformed before analysis. Sample size calculation was conducted for the original study which employed a randomized cross-over design (17), and was therefore irrelevant for the observational design of this secondary analysis. However, sensitivity analysis with the G*Power software determined that partial correlations of 0.21 and higher could be reliably detected with our sample size by the alpha level of 0.05 and power of 0.80.

RESULTS

We collected data from 40 participants (25 females and 15 males) who were either medical students (n = 9), fellows (n = 22), consultants (n = 8), or a nurse (n = 1). Their clinical experience ranged from 0 to 26 years (M = 4.26, SD = 6.52). The majority of participants (98%) had prior experience in simulation-based resuscitation training and felt competent in providing BLS (92%).

Visual Attention and Chest Compression Quality

Table 1 shows descriptive statistics of the tested eye-tracking parameters. The most salient AOIs were infant chest and ventilation mask (both ratios = 100%), followed by study nurse (59%) and ventilation bag (41%). These results were mirrored by significant differences in revisits among the AOIs (F = 51.19,

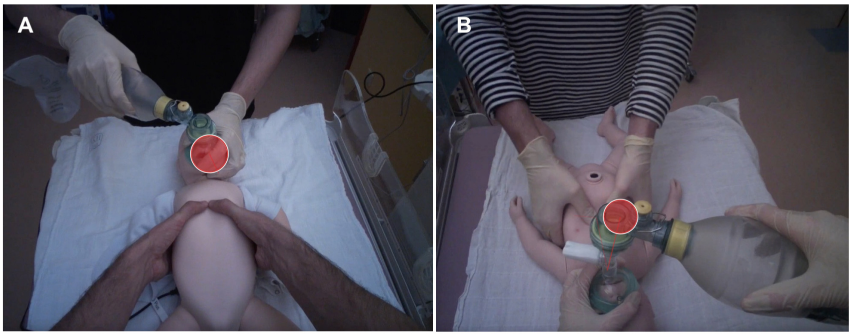

FIGURE 1 | Snapshots showing visual attention (red circle) of participants during the chest compression scenario **(A)** and the ventilation scenario **(B)**.

TABLE 1 | Descriptive statistics of the tested eye-tracking parameters.

	Ratio	Dwell time (s)		Revisits (n)		Transitions (n)	
	%	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
AOI (CC task)						66.36	44.72
Infant	100	131.04	46.30	29.36	19.56		
Ventilation mask	100	39.71	42.12	25.31	18.61		
Ventilation bag	41	1.42	4.26	1.28	2.89		
Nurse	59	0.59	1.10	0.74	1.93		
Others	97	6.67	9.71	9.67	14.34		
AOI (Ventilation task)						104.38	46.88
Infant	100	91.85	44.63	42.64	21.96		
Ventilation mask	100	70.76	41.78	40.18	14.28		
Ventilation bag	62	1.47	3.16	2.36	4.57		
Nurse	36	0.48	1.10	0.33	0.84		
Others	100	11.36	11.07	18.87	19.26		

AOI, area of interest; CC, chest compression.

$p < 0.001$), with participants returning their gaze to infant chest and ventilation mask more often than to any other AOI ($p < 0.001$; **Figure 2**). However, attention outside of task-relevant stimuli (the "others" AOI) was also common (ratio = 97%) and more frequent than attention paid to the study nurse ($p = 0.004$) and ventilation bag AOIs ($p = 0.011$).

Visual attention partly predicted the quality of CCs. Higher number of revisits to the area outside of the predefined AOIs negatively correlated with the total CC quality score ($r = -0.35$, $p = 0.031$; **Table 2**). Similarly, dwell time on the "outside" area negatively predicted the total CC quality score ($r = -0.38$, $p = 0.018$), whereas dwelling on infant chest positively correlated with percentages of correct CC rate ($r = 0.33$, $p = 0.044$; **Table 3**). The number of transitions between AOIs was unrelated to CC parameters. These results suggest that shifting gaze outside of the predefined AOIs, indicating distraction from the task at hand, may harm the quality of CCs, whereas focusing on the infant chest supports CC rate compliance.

Visual Attention and Ventilation Quality

Similar to the CC scenario, the most salient AOIs in the ventilation scenario were infant chest and ventilation mask (both ratios = 100%; **Table 1**). The study nurse AOI had a ratio of 36% and the ventilation bag AOI had a ratio of 62%. There were significant differences in revisits among the AOIs ($F = 98.60$, $p < 0.001$), indicating that some AOIs were revisited more often than others (**Figure 2**). Again, revisits to the infant chest and ventilation mask AOIs were more frequent than revisits to any other AOI ($p < 0.001$). Participants (ratio = 100%) also focused on other stimuli than the predefined task-relevant AOIs and revisited the "others" AOI more often than the study nurse and ventilation bag AOIs (both $p < 0.001$).

High number of revisits to ventilation mask ($r = 0.50$, $p = 0.002$), ventilation bag ($r = 0.46$, $p = 0.004$), and the "others" AOI ($r = 0.34$, $p = 0.042$) correlated with high leakage, and revisits to ventilation mask ($r = 0.41$, $p = 0.012$) and ventilation bag ($r = 0.36$, $p = 0.028$) were also associated with higher inspiratory tidal volume (**Table 2**). Participants with V_{Ti} in the 4–8 mL/kg range revisited the ventilation mask and ventilation bag AOIs less frequently than participants with V_{Ti} out of that range (36.2 vs. 41.2 and 2.0 vs. 4.5 revisits for ventilation mask and ventilation bag, respectively). Moreover, the overall high number of transitions between AOIs correlated with high leakage ($r = 0.40$, $p = 0.014$). Regarding dwell time, dwelling on infant chest was associated with lower leakage ($r = -0.34$, $p = 0.042$), whereas dwelling on ventilation bag correlated with

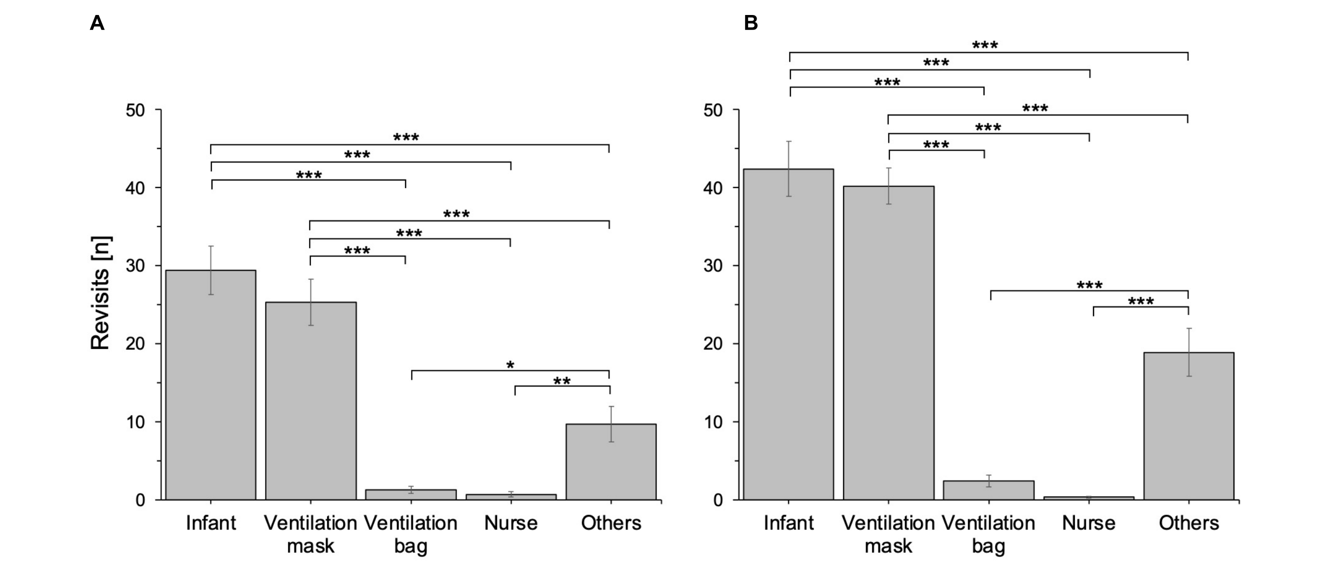

FIGURE 2 | Mean number of revisits to the study AOIs during the chest compression scenario **(A)** and the ventilation scenario **(B)**. Error bars are standard errors of the mean (SEM). *N* = 40, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

TABLE 2 | Correlations of revisits and transition count with chest compression and ventilation parameters.

	Revisits					Transitions
	Infant	Ventilation mask	Ventilation bag	Nurse	Others	
Chest compression						
Total CC score	−0.22	−0.02	0.04	0.04	**−0.35***	−0.24
Correct hand position	−0.19	0.00	−0.05	0.04	−0.27	−0.22
Full recoil	0.09	0.16	0.05	−0.14	0.04	0.13
Mean CC depth	0.04	−0.04	−0.07	−0.08	−0.18	−0.06
CCs with correct depth	−0.12	−0.17	−0.06	0.04	−0.29	−0.22
Mean CC rate	0.10	0.01	−0.12	0.20	−0.07	0.03
CCs with correct rate	−0.09	−0.13	−0.01	−0.18	−0.17	−0.08
Ventilation						
Inspiratory tidal volume	0.07	**0.41***	**0.36***	−0.15	0.29	0.30
Expiratory tidal volume	0.12	−0.06	−0.26	−0.11	−0.04	−0.01
Peak inflation pressure	0.13	−0.03	−0.31	−0.04	−0.11	−0.03
Mask leak	0.15	**0.50****	**0.46****	−0.05	**0.34***	**0.40***

*$p < 0.05$, **$p < 0.01$. Significant correlations are marked in bold.*

higher leakage ($r = 0.38$, $p = 0.020$; **Table 3**). Overall, these results indicate that participants who frequently switched their gaze between the ventilation equipment AOIs and other AOIs had troubles with the ventilation task at hand, whereas participants who dwelled longer on the infant chest dealt with the task better.

DISCUSSION

This study analyzed visual attention in a simulated pediatric resuscitation. We hypothesized that the infant and airway equipment would be the most salient cues for the resuscitation providers. In line with the hypothesis, we found that infant chest and ventilation mask (but not ventilation bag) were the most salient cues, as indicated by 100% ratio for both AOIs and the highest number of revisits to those AOIs. We further hypothesized that focusing on the infant and airway equipment would be related to CC and ventilation parameters. In a partial support of this hypothesis, we found that dwelling on the infant chest was associated with more correct CC rate in the chest compression task and lower leakage in the ventilation task, whereas dwelling on ventilation mask was unrelated to CC and ventilation parameters. Dwelling on ventilation bag and high number of revisits to airway equipment (both mask and bag) were even negatively related to mask leak during ventilations. Paying attention to the area outside of the predefined AOIs, indicating distraction from the task at hand, was overall negatively related to the total CC quality score.

TABLE 3 | Correlations of dwell time with chest compression and ventilation parameters.

	Dwell time				
	Infant	**Ventilation mask**	**Ventilation bag**	**Nurse**	**Others**
Chest compression					
Total CC score	0.26	−0.04	0.12	0.10	**−0.38***
Correct hand position	0.21	−0.06	0.00	0.06	−0.31
Full recoil	0.05	0.05	0.06	−0.09	0.03
Mean CC depth	−0.04	0.01	0.04	−0.05	−0.09
CCs with correct depth	0.05	−0.03	0.06	0.06	−0.20
Mean CC rate	−0.14	0.01	−0.09	0.19	−0.02
CCs with correct rate	**0.33***	−0.28	0.04	−0.22	−0.15
Ventilation					
Inspiratory tidal volume	−0.11	0.10	0.29	−0.08	0.13
Expiratory tidal volume	0.27	−0.25	−0.21	0.03	0.01
Peak inflation pressure	0.25	−0.17	−0.26	0.06	−0.01
Mask leak	**−0.34***	0.27	**0.38***	−0.15	0.17

$^*p < 0.05$. Significant correlations are marked in bold.

Our findings indicate that the infant chest is the most important source of information for high CC rate compliance and low mask leak during pediatric resuscitation, which is congruent with prior evidence observed in pediatric intensive care unit consultants (16). This is in line with the current resuscitation guidelines that call for visual monitoring of adequate chest expansion during ventilation procedures (19). Clinically, though, this may prove difficult in children (21) and especially in preterm infants (22). Correct assessment of ventilation is essential to deliver sufficient but not excessive respiratory support. Feedback tools such as respiratory function monitors, end tidal CO_2 measurements, or a coaching by observers may be profitably used to help in these situations (23, 24).

Even though high number of revisits typically indicates higher salience or importance of an AOI (20), we found that too many revisits to ventilation equipment and too frequent gaze transitions were associated with poor performance in the ventilation scenario (high mask leak, V_{Ti} out of optimal range). This was not expected and rather surprising. An explanation is that too frequent gaze shifts between the ventilation equipment AOIs and other AOIs were indicative of having troubles with the ventilation task. Participants might thus switch their gaze frequently to search for more information that would help them to better deal with the task at hand. Alternatively, the frequent gaze shifts might be indicative of insecurity and high nervousness which, in turn, negatively affected the ventilation quality. Our correlational design does not allow for drawing final conclusion for which of the above explanations is correct. Future research with experimental design is necessary to shed more light on the gaze shifting-performance causality.

However, the above suggestion about the relatively high numbers of revisits as a sign of nervousness or insecurity seems likely when considering results in the chest compression task. Contrasting the correlation between revisits to the infant chest and the total CC score with the correlation between dwell time on the infant AOI and the total CC score, we observed that the former correlation was negative and the latter positive (even though both non-significant). This indicates that frequent gaze shift away from the infant chest negatively correlated with overall CC performance, whereas dwelling longer on the infant chest without moving gaze back and forth too often (indicative of more stable, composed attention) predicted good performance. This also mirrors previously reported effects of stress on attentional resources and distractibility (25) and may be generalized to the simulation setting, as studies with simulated medical tasks typically produce acute stress responses in participants (26–28).

Notably, we found that paying attention outside of the predefined task-relevant AOIs (infant chest, ventilation mask, ventilation bag, and study nurse) correlated negatively with the total CC quality score and mask leak. The "others" AOI may be considered task-irrelevant and attention paid to this task-irrelevant AOI thus indicates distraction. Recent research has already shown that distracting healthcare providers either by external or internal stimuli during a resuscitation procedure resulted in lower quality of resuscitation (29–31). In those studies, distractors mainly operated as emotional stressors, with resuscitation circumstances being modified by the addition of noises, interference by actors, or cognitive tasks. In our study, however, no internal or external distractions were manipulated, yet many providers still diverted their attention from desired areas of focus, thereby diminishing the reception of information and harming their performance. The reasons for this distraction are unclear. It might be curiosity, insecurity, inexperience, feeling responsible for the overall management of the infant, and many others. Qualitative, semi-structured interviews could potentially help to better understand the underlying reasons for this distraction together with how to help providers stay focused on their task.

This study has both strengths and limitations. Strengths include objectively measured resuscitation performance, standardization, and a broad range of parameters tested. Moreover, the study extends prior research by directly testing the relationship between gaze behavior and resuscitation performance, which is a novel contribution given that recent researchers so far examined gaze differences of HCPs without directly relating the gaze to resuscitation performance (11–16). Limitations are the simulation-based character of the study not involving any real patients and the correlational design which does not allow for any causal interpretation of the findings. Our study design also did not allow to combine the components of resuscitation (CCs, ventilations) to give an overall estimate on pediatric resuscitation quality. Furthermore, our study included a rather small sample, which means that we cannot exclude the possibility of type-II errors (i.e., missed some important correlations). With a sample size of 40, however, the study was sensitive enough to detect correlations of 0.21 and higher. We tested revisits and dwell times on five different AOIs and related them to seven CC and four ventilation parameters. With this many tests we cannot exclude the possibility of a type-I statistical error. Indeed, if an adjustment was applied to the *p*-values for these correlations (e.g., Bonferroni, Holm-Bonferroni, and Chow-Denning), none would have been statistically significant. There is an ongoing debate about whether and when to use significance adjustments, with some researchers advocating the adjustments based on the results from computer modeling with random numbers (32), whereas other researchers recommending no adjustments because the data under evaluation are not random numbers but actual observations and adjusting *p*-values can potentially mask important findings (33). Given that significance adjustments are concerned with the general null hypothesis [i.e., that all null hypotheses are true simultaneously; (34)], it seems reasonable to use them for *post hoc* comparisons because the general null hypothesis has been already tested in the main model, yet the adjustments seem to be of little relevance for a sole assessment of individual relationships (e.g., in a correlation matrix). Still, due to small sample size and multiple tests, our results should be taken with caution and replicated with larger samples before final conclusions can be drawn. Finally, it would be interesting to measure effects of different levels of expertise, but there was a disproportional distribution of students, fellows, and consultants in our sample, which did not allow for meaningful comparisons. Learning more about the value and patterns of visual attention in experts remains an important issue for future research in order to improve current medical training for maximum benefits.

CONCLUSION

We examined patterns of visual attention in providers during a simulated pediatric resuscitation and found that concentrating on the infant's chest during both CC and ventilation tasks correlated with better CC rate compliance and lower mask leak. In contrast, focusing on task-irrelevant environment, indicating distraction, was related to poor outcomes. As recommended in the current pediatric resuscitation guidelines, trainers should teach providers to concentrate on patient chest for improved performance.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Medical University of Vienna. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

PG, MW, and FC conceived and designed the study, and wrote the manuscript. FE, MW, PG, and FC performed the study. KB and HS helped with coordination of the study and coding eye-tracking data. PG and MW analyzed and interpreted the data. KB, HS, and AB critically reviewed and revised the manuscript for important intellectual content. All authors approved the final manuscript as submitted and agreed to be accountable for all aspects of the work.

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OPINION
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Opinion Paper: Rationale for Supra-National Training in Neonatology

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INTRODUCTION

Clinical training in neonatology takes place where neonates are cared for, at the cot-side, in neonatal units. Neonatal units vary widely in size, specialization, resources, staffing and academic level. Among them, small units make up a large proportion which have more difficulties to offer structured training courses on site, local expertise on all relevant neonatal topics, and appropriate exposition of the trainee to high-risk cases. Although evidence-based medicine is widely accepted, training of physicians, including neonatologists, often follows ineffective learning methods, or even less favorable, learning by doing. When looking at the national training requirements and standards within Europe, there are large differences between countries. Some countries have training requirements, standards and national training courses in place other countries have none of this. Therefore, it is worthwhile to create a supra-regional or even supra-national training program that complements local clinical work on an individual basis to provide structured training and evidence-based education anywhere and anytime.

The European Society for Paediatric Research (ESPR) has long been committed to the education and training of medical doctors specializing in neonatology. Together with the European Board of Neonatology (EBN), which is a substructure of ESPR devoted to the design and implementation of a syllabus that comprises the theoretical and practical needs for the European Training in Neonatology, the European Training Requirements (ETR) in Neonatology has been developed.

The 2021 updated syllabus, the current ETR in Neonatology, is based on the previous 2007 syllabus version and has been approved by the Union of European Medicine Specialist (EAMS) in April 2021. Interestingly, the 2021 syllabus content was updated by the EBN members, but also critically incorporated and comments suggestions of national representatives of 30 European countries following two sequential surveys and face to face meetings. Each country pertaining to the EBN has a different national training curriculum to achieve the training standards required to exert as neonatologists. The aim of the ETR in Neonatology has been to harmonize training requirements within Europe to achieving a basic and reliable standard of quality in theoretical knowledge and practical skills alongside the European countries.

We present an online training concept that meets the needs of neonatal training situations and implements the latest effective didactic elements.

ANALYSIS OF THE TRAINING AND WORK SITUATION

The process of revising the 2007 syllabus and preparing the 2021 syllabus, the current ETR in Neonatology, included several expert meetings, surveys and targeted interviews to address and analyze the work and training situations of trainees in neonatology in Europe. This was done in a participatory process with the heads of neonatal and pediatric intensive care units, consultants of different levels, various medical professions such as surgeons and radiologists involved in the care of children, and educational specialists. The process was designed as action research: each participant was challenged to make a specific contribution to the new training, thereby changing and adding to the existing training practices. The premises and the outcomes were reflected upon and divided into seven categories, each offering specific insight.

1) Professional situation: Physicians specializing in neonatology do not start from scratch. They are trained physicians in pediatrics. This experience allows the use of elements of transfer didactics. It is not necessary to build up knowledge elements first to gain experience, but students can work and learn with existing routines.
2) Level of training: According to the Novice-to-Expert scheme (1, 2) (novice, advanced beginner, competent, proficient, expert) physicians specializing in neonatology are competent to proficient in many aspect. However, trainees, depending on their background, may be novice in different areas more specific to neonatology. This means for training to focus on skills acquisition only in selected areas. The training could immediately include reflective practice in general.
3) Knowledge structures: Looking at the required knowledge structures (3, 4) and use memory models, two types are needed: on the one hand, procedural knowledge, which enables diagnostic and therapeutic decisions tailored to a specific action situation; and on the other hand, declarative knowledge, which represents the knowledge space, i.e., the possible diagnostic and therapeutic measures, their possible applications, differences, advantages and disadvantages. etc.
4) Collaboration: A central element of clinical practice is inter-professionality. Although neonatologists are the case-leading physicians for neonates, different professions and specialties contribute to clinical success. Neonatologists must integrate their own activities with the routines and competences of others, and thereby make their own contribution to the management of the clinical situation. This means that cooperation, participatory management and communication are important premises of medical training in neonatology. In case-based learning sequences, not only the handling of the highly vulnerable patients is practiced, but also the collaborative management of the overall situation.
5) Multidisciplinary: Since children and in particular neonates are not legally responsible and cannot express their needs, wishes and hopes, a multidisciplinary and usual transgenerational situation arises. These situations are of mutual learning (5, 6).
6) Integration of Training with Organizational Learning: Trainees and the training itself should contribute to quality assurance and quality improvement in daily clinical work across the whole neonatal unit. Training is part of a learning organization and vice versa. Hence, training will accompany clinical practice and, conversely, the operational organization in the neonatal unit will be accompanied by training elements in which the physicians participate. Closely linked, trainee-driven projects will emerge between neonatal units and the training provider from guidelines to trainings to continuous improvement.
7) Uniqueness of Neonatal Medicine: One aspect makes training in neonatology particularly interesting and unique. It is the transition of the infant from intra to extra-uterine life. Due to the constant changes in the underlying physiological and pathological state, clinical decisions must involve few, insufficient assumptions and constant observation. This requires a great deal of experience. The challenge is to create training elements that can reduce the number of experiences in these rapidly changing situations and thus achieve a faster operational capability.

THE REQUIREMENT FOR EFFECTIVE TRAINING

Since the 1990s, the term 'evidence-based medicine' is a guiding principle in clinical decision-making. It means the conscientious, explicit and reasonable use of current best evidence in the care of patients (7). Research and clinical experience of experts is reflected in evidence-based guidelines and policies. Evidence-based education (EBE) (8, 9) goes in a similar direction. Educational practices should also be based on the best available scientific evidence, rather than tradition, personal judgment, or other influences. EBE can be summarized as evidence-based teaching, evidence-based learning, and school effectiveness research.

However, training and full immersion in evidence-based medicine does not mean that evidence-based principles are also followed in education. Tradition and personal judgment noticeably prevail in medical education, and EBE is largely unknown in clinical training of physicians. Thus, medical experts rely on the latest evidence for patient care, but train their young colleagues in an eminence-based fashion or leave the training to daily clinical practice.

Hattie (10) and his team performed meta-studies to examine the efficacy of various educational settings on learning performance as compared to settings without educational interventions. They observed that learning progress occurs even without a planned training intervention, which we all know as "learning by doing." This is more than questionable in clinical settings. Hattie et al. (11) has advanced this work in recent years. Both express the effectiveness of training settings in effect sizes (d). Beywl states that an effect size below <0 would be harmful; effects up to 0.15 can be achieved through development or experience even without training (learning by doing). Values >0.40 can be achieved by dedicated training in the real world, not only in the ideal world of research settings. Problem-based learning is slightly more effective with $d = 0.26$ than PowerPoint lectures ($d = 0.15$). Unfortunately, the effect of both methods is not measurable in the real world. To achieve significant effects in the real world, training should consist of elements such as performance assessment by professionals ($d = 1.29$), microteaching ($d = 0.88$), and cognitive task analysis using cases ($d = 1.29$) or with transfer strategies ($d = 0.86$). These all have effect values significantly above 0.15. The aim is to develop education with an effect size of $d > 0.70$ while avoiding all kinds of education with lower values e.g., non-didactic supplementary materials ($d = 0.32$) and classic case studies ($d = 0.37$).

It should be noted that learning by doing can take on different forms, depending on the level of educational intervention by a supervising practitioner. By itself, learning by doing is not necessarily deficit as an educational model, but rather in its implementation. Merritt et al. (12) presents a model for clinical education in which learning by doing is part a detailed learning circle under the guidance of experts. This type of structured and conscious apprenticeship requires education of the preceptors which may be a barrier to implementation.

The even greater challenge is to get these methods accepted and embraced in training of all types of medical specialists, e.g., in neonatology. It is easy to name a list of methods, but it is almost impossible to create medical education with elements that have an effect size of $d > 70$. In fact, the authors are convinced that medical education can largely be accelerated and patient care improved, not only in neonatology, if evidence-based education becomes the standard. Thus, the novelty of this communication is that a working group for medical education representing multiple nations across Europe agree not only on the importance of EBE but also on the feasibility of implementation and further created tools for implementation. Consequently, appropriate materials for online modules have been developed.

A summary of powerful methods used in EBE are the following: Individual exercises are structured to promote transfer strategies ($d = 0.86$). We evaluate the individual participant contributions and how far they were thought over (control of learning effort $d = 0.77$). Practical experiences and procedures are shared and analyzed in reciprocal learning ($d = 0.74$) with scaffolding by tutors ($d = 0.82$). Processing consists of making summaries ($d = 0.79$), elaborating and organizing concepts. Decision trees are used in own and reported situations ($d = 0.75$). For the assignments we provide elaborated didactic supporting material ($d = 0.72$) that is adapted to different levels (to prior knowledge, $d = 0.93$). For certain complex tasks, individual group members work out different aspects in subject groups and then return to their home group (group puzzle, $d = 1.20$).

THE OVERALL CONCEPT OF THE SUPRA-NATIONAL ONLINE MASTER'S PROGRAM IN NEONATOLOGY

The newly developed online program in neonatology accompanies individual clinical training and implements our research findings and latest evidence-based education knowledge in effective learning processes. The rational for the involvement of supervisors, tutors, peer groups, lecturers, other professions and the commitment of parents is summarized in the following paragraphs and in **Table 1**.

First, constant performance assessment ($d = 1.29$) is highly effective and, based on it, numerous training components can be individualized in a way we all know from personalized sport programs, e.g., in the gym. For the performance assessment, the trainee appoints a specific supervisor in the workplace who will act as the main preceptor for each trainee. The Supervisor will also be consulted for all aspects of the learning organization, such as the updating or creation of standards, the organization of internal trainings by the students, or the implementation of continuous improvements as a training project.

Second, online small group tutoring is used to implement strategies including microteaching ($d = 0.88$) (13), cognitive task analysis using cases ($d = 1.29$) (14, 15), transfer strategies ($d = 0.86$) (16) and scaffolding. The program works with regional groups and a tutor who knows the regional conditions and can guide the transfer of the learning concepts taking into account regional, organizational, hierarchical, technical, cultural and other conditions. Tutors are neonatologists with a strong social commitment and training experience, who can empathize with the trainees and coach them in small groups comprising no more than 5 participants. A second type of transfer strategies is important: trainees in neonatology already have clinical experience with children. They can therefore learn through transfer strategies from earlier experiences and do not need to build up basic knowledge first. Immediately after each decision, feedback is given in the form of the decision of an experienced neonatologist. This allows the trainee to compare the approach and adapt procedures in decision making to the new situation in neonatology. Only if the student cannot understand the new procedure he will consult the basic resources.

Third, peer groups are useful for reflecting on one's own solutions in given cases or one's own clinical routines in a friendly but fostering atmosphere. Participants are analyzed in reflective or reciprocal learning ($d = 0.74$) sessions (17, 18). These settings are highly effective in changing routines, attitudes and values, provide feedback and promote socialization (19, 20).

Fourth, one of the main activities of neonatologists is decision-making related to diagnostic procedures and therapeutic or supportive interventions in quickly changing situations. To address this specifically we use a procedure that we call step-by-step cases. In each case, only the current information is presented (on the phone you learn…) with a question about the first decisions (what do you ask?) and usually an inter-professional aspect (what do you expect the nurse to do?). Only after entering the answer the next step of the case is presented to the student.

TABLE 1 | Training techniques in the master of neonatology.

What	Who	Where	How
1) Constant performance assessment	Supervisor	Hospital, clinical workplace	Regular evaluation of implementation of tasks in clinical practice, documentation in a portfolio and plot of the progress
2) Microteaching, cognitive task analysis and transfer strategies	Tutor	Online	Illustrated and animated cases requiring step-by-step decisions by the student. If needed the student can consult basic knowledge resources provided before entering the decision. The whole process is filed and visible to the tutor, and thus can later be taken up in microteaching or assigned to peer group discussions.
3) Reflective or reciprocal learning	Peer group	Online	Student solutions and portfolio cases are analysed by peer groups in reflective or reciprocal learning
4) Decision-making related to diagnostic procedures, therapeutic or supportive interventions	Tutor, Peer group	Online	In each case scenario, only the so far completed and current information is visible to the student with a question about the next decision (e.g., what are your top 5 answers or what specific additional information you need?) and usually an inter-professional aspect is addressed (what do you expect the nurse to do?). The respective answer triggers the next step
5) Inter-professional learning	Parents, health care professionals	Online, hospital, clinical workplace	In special sessions parents will present their own experiences. Mixed professional peer groups can develop strategies for their practice and clinical setting on how to improve.
6) Targeted knowledge transfer	Invited lecturers	Online	Specific topics are presented in catchy webinars and discussions moderated by experts engage students and tutors likewise
7) Monitor with the concept of Entrustable Professional Activities (EPA)	Supervisor	Hospital, clinical workplace	EPA guide a graded increase in autonomy and responsibility toward readiness for the unsupervised practice of key tasks of the profession. In our master's programme goals are formulated as EPAs, place decision-making as the basis for entrusted activities at the center of learning, and also adopt the EPA evaluation

Depending on the case, the student receives after each step or at the end of the case story the information what colleagues did in the situation and secondly further information about the course of the case. This format is easier to implement online than on paper.

Fifth, inter-professionality is also a value-based system and needs to be addressed with training participants. This can easily happen online, when e.g., midwives and nurses participate in certain joint training modules of the physicians' continuing education. Furthermore, inter-professional learning enriches the educational outcomes of all involved persons and creates real world situations. Parents will present their own experiences. Peer group can develop strategies for their practice and clinical setting on how to improve.

Sixth, albeit power point presentations and webinars have an effect size of <0.4, we will use webinars coupled to moderated discussion to provide topical insights and latest summaries from dedicated lecturers in specific fields to a broader audience as targeted knowledge transfer.

Seventh, Entrustable Professional Activities (EPAs) were introduced to operationalize competency-based medical education and to facilitate the guidance and evaluation of learners in clinical workplaces (21). The EPA concept aims to guide a graded increase in autonomy and responsibility toward readiness for the unsupervised practice of key tasks of the profession. Entrustment decision-making has received much attention recently (22).

In our master's programme, we formulate our goals as EPAs, place decision-making as the basis for entrusted activities at the center of learning, and also adopt the EPA evaluation scale (23), which show the levels of autonomy in professional activity. We follow the tips for implementation from Peters et al. (24).

At the end of each training unit, comprising thematically structured module parts with independent learning, tutored peer group learning and other training items, there is direct online contact with specialists. During the modules, questions, uncertainties and solutions are collected—always with the projection by the tutor that these should be clearly formulated for the final meeting with the specialist. This creates commitment and deepens the discussion.

Table 1 summarizes all training techniques applied in the Master of Neonatology. They are used by tutors, peer groups or guests in online training and supervisors in the connected clinical training settings.

CONCLUSION

After more than 2 years of work field analyses and development, we conclude from the feedback received by the authors, instructors and experts so far, that a supra-national online training program can meaningfully improve clinical work and that even sophisticated concepts can be translated with professional guidance into online materials, assignments and organizational structures.

The training organization with regional tutors, local supervisors and other professions involved and the tailored contributions by keynote lectures are subject to final tests. The end result will be a suitable concept for personalizing medical education adapted to the respective regional care situation despite the online setting and supranational organization.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Video recording emergency care and video-reflection to improve patient care; a narrative review and case-study of a neonatal intensive care unit

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As the complexity of emergency care increases, current research methods to improve care are often unable to capture all aspects of everyday clinical practice. Video recordings can visualize clinical care in an objective way. They can be used as a tool to assess care and to reflect on care with the caregivers themselves. Although the use of video recordings to reflect on medical interventions (video-reflection) has increased over the years, it is still not used on a regular basis. However, video-reflection proved to be of educational value and can improve teams' management and performance. It has a positive effect on guideline adherence, documentation, clinical care and teamwork. Recordings can also be used for video-reflexivity. Here, caregivers review recordings together to reflect on their everyday practice from new perspectives with regard to context and conduct in general. Although video-reflection in emergency care has proven to be valuable, certain preconditions have to be met and obstacles need to be overcome. These include gaining trust of the caregivers, having a proper consent-procedure, maintaining confidentiality and adequate use of technical equipment. To implement the lessons learned from video-reflection in a sustainable way and to continuously improve care, it should be integrated in regular simulation training or education. This narrative review will describe the development of video recording in emergency care and how video-reflection can improve patient care and safety in new ways. On our own department, the NICU at the LUMC, video-reflection has already been implemented and we want to further expand this. We will describe the use of video-reflection in our own unit. Based on the results of this narrative review we will propose options for future research to increase the value of video-reflection.

KEYWORDS

video recording, emergency care, video review, clinical audit, quality improvement, video-reflection, videotape recording

Introduction

Video recordings offer the possibility to visualize clinical care in a comprehensive and objective way. Due to the emergent nature of critical care, recordings proved to be a valuable addition in evaluation and improvement (1, 2). The environment in emergency care can be chaotic and protocols are not always followed. This makes it difficult to make the necessary quality improvements. Recordings can be used to identify new areas of improvement in emergency care (3). Reflection by caregivers show them the aspects of care they enact without conscious awareness. The clinicians then have the ability to reflect on their own habits and intervene to improve future clinical outcomes (4). Video-reflection is affordable and relatively easy to initiate with technical equipment available worldwide. So far, reflection on recordings of emergency care has been used for studies in neonatology, trauma care, obstetrics, pediatrics and in cardiac arrest teams, but not routinely during daily care (5). Although these studies show video-reflection has the potential to improve teamwork and quality of patient care, it remains unclear what different types of video-reflection are often used and how they differ in improving quality of care. The aim of this narrative review is to describe the different applications of video recording in clinical care and their effect. We discuss preconditions and obstacles of video-reflection and explore how video-reflection can be used more routinely to improve care. On our own department, the NICU at the Leiden University Medical Center, we have already implemented video-reflection of neonatal resuscitations. At the end of this review we will describe the use of video-reflection in our own unit. In light of the results of this narrative review, we will propose how future studies can enhance video-reflection on our neonatal department.

Materials and methods

This narrative review is based on a literature search which was performed in collaboration with a medical information specialist. To identify all relevant publications about video-reflection or audits of interventions in healthcare we performed searches in the bibliographic databases PubMed, EMBASE.com and Emcare (*via* Ovid) from inception to October 7th, 2021. Search terms included controlled terms (MeSH in PubMed and Emtree in Embase/Emcare) as well as free text terms. Search terms expressing 'video' were used in combination with search terms comprising 'clinical audit.' The primary researcher (VH) conducted a screening and made a list of articles that would be full-text assessed. This included all articles on different methods of video-reflection in emergency care. The literature was supplemented with studies found by reviewing the references of the included studies. A search strategy can be found in the **Supplementary material**.

Using recordings for assessing quality of care

Compliance to guidelines

Video recordings can help compare work-as-done with work-as-imagined. Work-as-done is a term describing the daily activities of everyday clinical work. Healthcare workers adapt and adjust their actions according to the specific situations they face and the needs of the patients they are caring for. Work-as-imagined describes the manner in which it is assumed that people will do their work. It refers to the way people who make guidelines or regulations believe the work should be carried out. There may be a considerable difference between what people are expected to do and what they actually do (6). Recordings can be used to assess the actual guideline adherence. Studies using video recordings in emergency care have shown that caregivers often deviate from the guidelines (7–10). These insights give the opportunity to evaluate and discuss the prevailing guidelines and adapt them where needed (8, 11). Although more studies are needed to measure the effect of reevaluating guidelines, assessment of recordings of clinical care can emphasize the continuous need for reinforcement of adherence (7, 10, 12).

As a result of this, protocols can also be expanded or adjusted. Taylor et al. used video recordings to create specific time goals for key steps in trauma resuscitation to reduce the total amount of time spent in the trauma bay. Plan-Do-Study-Act cycles were used to define time goals in order to improve quality (13). Aydon et al. (14) assessed leadership and handover during the first hour after admission to the NICU, which resulted in implementation of extra guidelines for handover. Furthermore, video recordings have been used to evaluate the rate of compliance to the use of protective clothing and accessories to prevent exposure to blood or body fluids (2). Even differences between centers in various countries, with their own local guidelines, can be made visible by assessing video recordings (15).

Non-technical skills

Guidelines focus mainly on technical aspects of care. However, it is also important to include non-technical aspects for a good quality of care. Studies show non-technical aspects, like communication, leadership and teamwork, can be assessed well with video recordings (12, 16–19). Williams et al. (20) used the Crew Resource Model from the aviation industry to study the relationship between teamwork behaviors and errors using video recordings. They observed that more vigilant teams committed fewer errors. Nadler et al. (21) used video recordings of neonatal resuscitations and scored them on teamwork, guideline adherence and temporal control of the resuscitation procedure.

Using recordings for video-reflection

Video recordings can also be used to allow caregivers to reflect on their practice and evaluate the care given. This so called video-reflection enables caregivers to see what actually happened during a procedure and compares this with their recollection of what happened. Videotaping care has the benefit that it allows for assessment at any hour, without intrusion of an observer (22). The camera is an impartial observer and can create a more detailed recollection of interventions than the caregivers themselves (17). This is confirmed by Schilleman et al. in a study showing that documentation of neonatal resuscitation in the medical file is often inaccurate and differs from what is seen in video recordings of the same resuscitation. Recordings can clarify documentation because they give an unbiased view (23). Next to that, recordings can be an addition to debriefs because it provides caregivers with more detailed feedback of their performance. Nadler et al. (21) showed that debriefs supported by recordings improved teamwork at subsequent resuscitations. Nevertheless, when caregivers know they are recorded, the Hawthorne effect may occur: behavior can be changed because they are aware they are being observed. However, this is usually a change for the better (17, 24).

Multiple studies have been carried out which try to improve quality of care by using recordings for video-reflection with the caregivers. Scherer et al. (25) showed that guideline compliance improved more when video recording was used to reflect on Advanced Trauma Life Support (ATLS) when compared to verbal feedback. Other aspects in trauma care, besides guideline compliance, that improve after video-reflection are resuscitation technique, adherence to assigned tasks and a decreased variability between caregivers (3, 24, 26, 27). It is particularly important for pediatric trauma centers to maintain their ATLS skills as they treat critically injured patients with a lower frequency than adult trauma centers (24). The long term effect of video review has also been studied. Raphael et al. (28) showed video-reflection increased the compliance rate to the time-out process before an intervention. This improvement remained for at least 2 years.

In neonatal care, Root et al. studied a cohort of infants born before and after implementation of weekly video reflection and compared the recordings to the resuscitation guidelines. Providers complied more often to guidelines and correct documentation increased from 39 to 65% in the period after implementing weekly video-reflection sessions (29). Video-reflection is considered most effective in combination with skill training or quality improvement programs in improving technical as well as non-technical skills (12, 22). After a combination of a skill training program and video-debriefing was introduced, Skåre et al. (30) showed an improvement in time to effective spontaneous breathing and in compliance to guidelines. The ultimate goal of video-reflection is often improving patient outcomes by improving the practice of the caregiver. The perspective of the caregiver is, however, not often the objective of a study. It might be interesting to see the effect of video-reflection on for example their level of confidence or relaxation during interventions which ultimately also has an effect on patient care.

However, the catch with video-reflection is how to actually use the findings for education or improvement in a way that is effective and sustainable. It is recommended for future team trainings to implement the findings of video reflection in a feedback system and to follow the changes that occur over time (31). Data acquired from video review must be used to drive change, otherwise it becomes a mundane task (32). It is recommended to conduct video-review regularly, for example weekly, with a predefined timeslot and integrated in training and education to avoid a decline in skills and knowledge after it is learned (33). This will create a cycle of evaluation (by video-reflection), training and re-evaluation (30, 31, 33). However, future research is needed to assess different methods for sustainability. This can help to maximize the efficiency of video review (5).

Using reflexivity to learn from everyday practice

While recordings can be used to focus an individual on their errors or non-compliance, there is also a different approach. Reflexivity uses recordings to enable caregivers to review recordings together to learn from interventions, context and conducts and collaboratively find ways to improve care (4, 34). Where reflection is personal and focused on specific aspects of caregivers own conduct, reflexivity is broader and focused on how implications of learning can impact the context in which they work together. Reflexivity is especially useful to improve quality of complex care. So far, methods such as simulation-based education and debriefing have been used to improve quality of care (35, 36). However, to learn from aspects of care that caregivers enact unconsciously, that are unexpected, or how every patient and intervention requires a different approach, real-life recordings are required (6). When showing these recordings to the front-line staff, caregivers can obtain different perspectives and their input can be used as the base for quality improvement. Reflexivity can be the next step improving quality of complex care (4, 37).

Hor et al. used reflexivity to design the space in an intensive care unit to maximize communication effectiveness. In the IC ward an open-plan design was used for accessibility. However, the open space gives more opportunities for interruptions as well. This study showed how video-reflexivity can be used to establish improvement as an ongoing process instead of a response to adverse events. They used solutions such as changes in behavior and reflection to improve communication (38). Reflexivity has also been used to explore the impact of health professionals on the facilitation of skin-to-skin contact within the first two hours after a caesarian section. A study by Stevens et al. sheds a light on the amount of contact between mothers and their babies, which was low, physically as well as emotionally. Here, video-reflection has been used to visualize care in a new way resulting in an increased understanding of what happens in practice. This kind of perspective is often overlooked or not paid attention to (39). Crenshaw et al. (40) described how video-feedback, reflection and interactive analysis could be an innovative approach to improve nurse leadership practices to reduce nursing shortage. Lastly, Sarcevic et al. examined leadership structures in a trauma center to identify weaknesses. As a diversity of patients with different injuries is admitted to trauma centers, effective leadership is essential to evaluate and treat each patient in the best way. In this study, video-reflexivity was used to identify leadership structures. Suggestions for technology design to support teamwork and patient care were made, e.g., using a smart-badge to enable more efficient role-identification or digital pen and paper technology (41).

In summary, video-reflexivity can be used to visualize care and social structures in new ways to drive continuous change and improvements. Especially in emergency care the environment can be chaotic. Through reflexivity caregivers can get a full overview of all the different aspects of emergent care and give input on improving the quality of care.

Preconditions for the organization of video-reflection

Even though we live in a social media era where recording is part of everyday life, recording care is not yet a general practice (5, 42). Caregivers may find it difficult to record their practice and reflect on it with others. They may feel exposed, embarrassed and vulnerable because of the possibility of negative feedback on their behavior (43). Studies have shown that the solution is to engage the caregivers in the goal of video reflection and to obtain a feeling of trust and safety (44, 45). McNicholas et al. (45) hypothesized in their review that when caregivers have had a higher exposure to simulation or review training during their education, they had less anxiety when being recorded. However, those who feel uncomfortable when being recorded should be given the opportunity to have an alternative location or to control the activation of the cameras (44).

To activate the caregivers, Lloyd et al. recommends to generate short-term wins to create a sense of urgency. For example, when the implementation of a new checklist has improved verbal skills of the team leaders during intubation, this should be visible for the entire organization and celebrated (46). Dumas et al. (42) emphasized data of recordings should only be accessible to approved entities and be reviewed only at approved venues (e.g., with only peers present). Regardless, when a department has actually implemented video recordings, it is often accepted by caregivers who are participating (26). A study by den Boer et al. showed caregivers on the department of neonatology experience recording and reviewing neonatal resuscitation beneficial for learning and improving neonatal resuscitation skills (47). Shivananda et al. (48) showed a high rate of willingness and acceptance after implementation of video-review.

Still, common hurdles of video review that remain within a team are technical challenges like functioning of equipment and storing of videos. Other challenges are time and resource constraints, as it is time consuming to prepare video-reflection sessions and storage capacity needs to be considered carefully before the start of a video-reflection project (31, 49). There is still no existing or dedicated installation specifically designed for emergency medicine that enables recording and storing medical videos in a safe manner. Every hospital finds their own way in this.

Cultural differences may also play a role in implementing video-reflection, but so far no studies have analyzed this. However, studies have shown that ethical and legal issues play a role (26, 31, 45, 50). Different standards and formalities of ethical committees exist and differ between centers and countries, which results in a variation in implementation of video-reflection regarding consent, data acquisition and storage (33). As the focus of the recordings is not the patient, but the quality of care provided by the caregivers, the consent procedure nearly always includes consent from the caregivers. In emergency care, informed consent may be difficult to obtain from the patient. This can make it hard to get legal permission for recording. Studies that record without consent from the patient often make review of recordings part of a safety and quality assurance process where consent is deemed unnecessary (51). The question remains if this goal is more important than the patient's right of privacy (5). When the sole goal of video reflection is quality assurance, the recordings may be partially protected from medicolegal consequences by protective acts. However, local regulations need to be considered carefully by each center when implementing video-reflection.

Technical aspects and future developments

When comparing a camera to an observer who is present to assess care, the observer present can be biased or miss certain aspects because they need to take it all in at once. Observers

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watching a recording however, can assess communication and leadership independently from technical quality (16). However, assessment of recordings can still be difficult. For example, Oakley et al. found that it was challenging to accurately assess the clinical state of the patient on recordings without complementary vital signs (9). Recordings offer only a restricted view of the context and effectiveness of interventions in emergency care. For example, Gelbart et al. (52) states that assessment of degrees of stimulation, color and Apgar scores are vulnerable to subjectivity, as is the context of the team functioning. When reviewing a video, one can be blind to aspects that are obvious to the team that was present (5).

As a solution, recordings can be made more all-encompassing by adding vital parameters that are monitored to the recordings. In neonatal resuscitation, a Respiratory Function Monitor (RFM) has been used to provide information

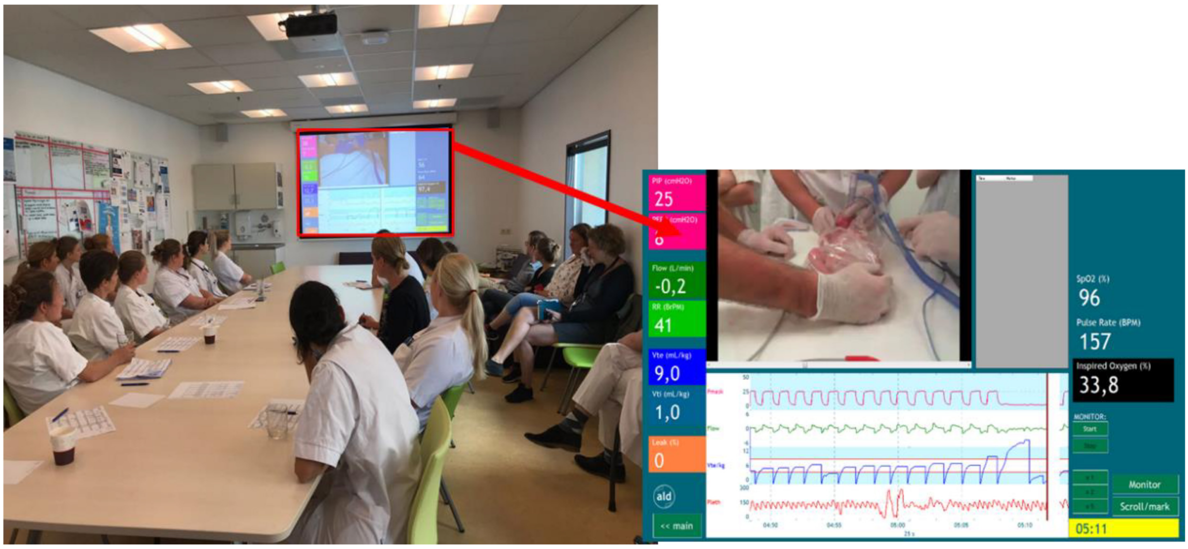

FIGURE 1
Video-reflection of a neonatal resuscitation on the Neonatal Intensive Care Unit (NICU) of the Leiden University Medical Center (LUMC) from 2014 until 2021. Recordings of the hands of the caregivers and the Respiratory Function Monitor (RFM) are visible.

FIGURE 2
Video-reflection of a neonatal resuscitation from 2021 onward. Recordings of the hands of the caregivers, the respiratory function monitor and the resuscitation room are visible, with addition of audio. During the video-reflexive sessions, the focus is on the context.

on the physiological parameters of infants (53). Van Vonderen et al. (54) showed how the combination of the physiological parameters and recordings can improve quality and provide more useful feedback during review. The vital parameters and the recording complement each other and visualize the effect resuscitation procedures achieve (55). This could be beneficial to interpretation of recordings during video-reflection.

Another method to make recordings more comprehensive is to add recordings of eye-tracking glasses. These give a unique point of view, e.g., the healthcare providers' gaze. Wagner et al. showed that it is feasible, comfortable and has educational benefits. It can even be used for live time streaming to observers that are not present in the same room (56). Larsen et al. (57) showed it is effective for conducting research. In pediatric trauma simulation, research on eye-tracking showed it is feasible to use (58). Also, Dewar et al. investigated the use of body-worn cameras. Healthcare workers did not think it negatively interfered with carrying their job. It could also be a beneficial tool to analyze team performance (59).

Technology continues to develop and recordings are made more all-encompassing by adding vital parameters of the patient. This helps to understand complex care and team challenges. In trauma care, a so called Trauma Black Box has been developed. A black box from aviation contains a Flight Data Recorder where dozens of measurements from the airplane are stored combined with voice recordings from the cockpit. In emergency care, combined recordings of sound, video and vital parameters can also create a 'flight recorder,' e.g., it showcases a detailed recollection of what exactly went down during an intervention. This novel technology can be used to drive change and improve patient safety in the future (60). A different approach is using a video-based framework analysis to identify for example latent safety threats to patient safety during (61, 62). Fitzgerald et al. (63) even showed how recordings can help generate real-time algorithms to improve trauma resuscitation by analyzing preventable mortality and morbidity.

Putting it into practice: a case-study of the neonatal intensive care unit (NICU) at Leiden University medical center (LUMC)

Video and physiological parameter recording of neonatal stabilization was implemented at the Neonatal Intensive Care Unit (NICU) of the Leiden University Medical Center (LUMC) in 2009. Since 2014 weekly and plenary review sessions are held where recordings of neonatal stabilization are reviewed, focused on mostly on technical aspects (**Figure 1**). Recording and reviewing resuscitation is considered highly beneficial in our department for learning and improving resuscitation skills and is recommended by participating providers (64). It has proven to be a valuable tool for asking and giving objective feedback and to have educational benefits (29, 47). The recurring review sessions were said to enhance integration of lessons learned in the daily routine and improve patient safety (8, 47). Reviewing of neonatal interventions has become part of standard care in our department in the last 8 years and caregivers are used to recording their practice and to reflect on it on a regular basis. Recordings of neonatal stabilization are even reviewed with parents, who consider this to be valuable and reported positive experiences (65). Currently, caregivers even ask for recordings of their interventions to be reviewed.

Our department want to continue using video recordings to improve patient care and safety in new ways. Using the insights from this review, we propose a set-up for a future study on the implementation of video-reflection and using it to improve quality of care (**Figure 2**). The focus of the reflection sessions will be on daily neonatal interventions and their context, on reflecting multidisciplinary instead of individual assessment and on interacting with the members from both medical and nursing staff to retrieve their perspective. We use eye-tracking

FIGURE 3
Use of the Tobii eye-tracking glasses on the Neonatal Intensive Care Unit (NICU)of the Leiden University Medical Center (LUMC), which give a unique point-of-view recording.

glasses (**Figure 3**) to have an extra point of view and we have started recording intubations and sterile line insertions. Neonatal resuscitation will be recorded with multiple camera's, including a camera showing the hands of the caregivers and the infant, next to a camera with room-view (**Figure 2**). To evaluate non-technical skills we will also add audio to our recordings. Combining these recordings will allow for reflection of technical aspects as well as non-technical aspects. We will implement findings that are derived from the weekly reflexive sessions. Also, we will investigate the short and long term benefits for patients and the quality of care and collect feedback from caregivers. Our goal is to discover how to make implementation of findings continuous and sustainable, as this has not yet been studied. Lastly, we will write a manual for other departments who wish to start using video-reflection. We aim to describe the success factors and boundaries that need to be overcome to maximize the potential video-reflection has to offer.

Summary and future perspective

Video recording in emergency care has developed in many ways in the past years. It has been used as a tool for research and gives an objective view on work-as-done. Also, it has been used to improve care by showing recordings to the caregivers themselves which enables reflection and reflexivity on their actions. Still, it remains unclear how video-reflection can be best used to improve care or integrated in education to drive change. Although reviewing recordings in emergency care has been studied, this is mostly on the effect on guideline adherence or clinical skills. The improvement for long term and short term outcomes for the patient and the caregiver are still subject of research. Therefore, we suggest future studies should focus on how video-reflection is best implemented and used to improve quality of care.

Author contributions

VHee and RW drafted the initial version of the manuscript. All authors participated in critical revision of the manuscript for important intellectual content, approved the final manuscript as submitted, and agree to be accountable for all aspects of the work.

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Conflict of interest

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Supplementary material

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The “chicken-leg anastomosis”: Low-cost tissue-realistic simulation model for esophageal atresia training in pediatric surgery

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Introduction: Shifting the training from the operating room (OR) to simulation models has been proven effective in enhancing patient safety and reducing the learning time to achieve competency and increase the operative efficiency. Currently the field of pediatric surgery only offers few low-cost trainers for specialized training and these feature predominantly artificial and often unrealistic tissue. The aim of this study was to develop an easy access low-cost tissue-realistic simulation model for open training of esophageal atresia and to evaluate the acceptance in trainees and junior pediatric surgeons.

Materials and methods: The model is fashioned using reconfigured chicken skin from a chicken leg. To create a model of esophageal atresia, the chicken skin is dissected off the muscle and reconfigured around a foley catheter balloon to recreate the proximal pouch and a feeding tube to recreate the distal pouch. Surrounding structures such as the tracheo-esophageal fistula and the azygos vein can be easily added, obtaining a realistic esophageal atresia (Type C) prototype. Evaluation of model construction, usage and impact on user were performed by both a self-assessment questionnaire with pre- and post-training questions as well as observer-based variables and a revised Objective Structured Assessment of Technical Skills (OSATS) score.

Results: A total of 10 participants were constructing and using the model at two different timepoints. OSATS score for overall performance was significantly higher ($p = 0.005$, $z = -2.78$) during the second observational period [median (MD): 4,95% confidence interval CI: 3.4, 5.1] compared to the first (MD: 3, 95% CI 2.4, 4.1). Self-reported boost in confidence after model usage for performing future esophageal atresia (EA) repair and bowel anastomosis (BA) in general was significantly higher (EA: $U = 1$, $z = -2.3$, $p = 0.021$, BA: $U = 1$, $z = -2.41$, $p = 0.016$) in participants with more years in training/attending status (EA MD:5, BA MD: 5.5) compared to less experienced participants (EA MD: 1.5, BA: 1).

Conclusion: Our easy access low-cost simulation model represents a feasible and tissue realistic training option to increase surgical performance of pediatric surgical trainees outside the OR.

KEYWORDS

pediatric surgery, esophageal atresia (EA), training, simulation, anastomosis, surgical skills

Introduction

Training in pediatric surgery notably faces the challenge of acquiring experience in rare diseases, complex procedures and small operating fields (1). In the last decade changes to the health system have disrupted the traditional paradigm of surgical training, where the resident gradually acquires autonomy in the operating room, further hampering the quality of pediatric surgical training (2). Indeed, the increased interest in patient safety and operating room (OR) efficiency resulted in greater involvement of attending surgeons in the OR, reducing the resident's autonomy (3), whilst duty hours restrictions have concretely hindered the opportunities of involvement in acute/emergency case management. The result is that an increasing number of graduating residents are not sufficiently prepared for independent practice (3).

Simulation training has been proven effective in enhancing surgical skills, reducing the learning time to achieve competency and overall improving patient care (4). As such, interest in this field is currently rising in pediatric surgery training programs (1, 5–7). Ultra-realistic high-end surgical training units are evolving, but are often cost intensive and limited to wealthy clinical institutions. Animal trainings are similarly expensive, other than hard to obtain and ethically questionable (8). Only a few low-cost trainers for specialized training in pediatric surgery are available with predominant artificial and mostly unrealistic tissue (5, 9, 10). Based on these premises, we decided to develop an easy access low-cost tissue-realistic simulation model for esophageal atresia on the basis of a chicken-leg pyeloplasty model published in 2006 (11) and evaluate its effect in enhancing the performance of trainees and junior attending pediatric surgeons.

Materials and methods

The models are fashioned using reconfigured chicken skin from a chicken leg (**Figure 1**). To create a model of esophageal atresia, the chicken skin is dissected off the muscle and reconfigured around a foley catheter balloon to recreate the proximal pouch and tubularized around a feeding tube to recreate the distal pouch and tracheo-esophageal fistula (TEF). Surrounding structures such as the azygos vein can be easily added, obtaining a realistic esophageal atresia prototype. Varying the distance between the two ends, as well as adding the presence of a distal or proximal tracheo-esophageal fistula allows the creation of any esophageal atresia type. Finally, the use of a disposable kidney-dish further increases operative details by simulating the thoracic cavity and the actual surgical conditions.

The complete list of materials and approximated costs required for the model is described in **Table 1**.

Our study was conducted on a prototype of a type C esophageal atresia (**Figure 1A**). All residents and junior attending pediatric surgeons of our department were included in the study, as well as the medical students rotating in the pediatric surgery ward at the time of the study. All participants performed the training twice, at a two weeks interval (t1; t2).

The first session began with the view of an instruction video followed by brief comments from the examiners regarding tips and tricks of model construction and esophageal atresia repair. In the second session the participants could view the video once again, but no additional comment was given. The final instruction video was supplemented with the most given comments on creating the model and can be viewed at http://www.pedsurgtraining.com/videos (video "chicken-leg esophageal atresia - assembly instructions"). The complete instruction guide is shown in the **Supplementary material 1**.

Before each training, participants were asked to give information regarding their surgical experience in bowel anastomosis and esophageal atresia repair and in particular to subjectively evaluate their confidence in performing an esophageal atresia repair on their own. After each session, the candidates were again asked to fill out a questionnaire evaluating the model, as well as their acquired confidence in performing a bowel anastomosis or an esophageal atresia repair (**Supplementary material 2**). These self-reported items have been then statistically analyzed.

All candidates fashioned their own model and then performed the atresia repair as shown in the training

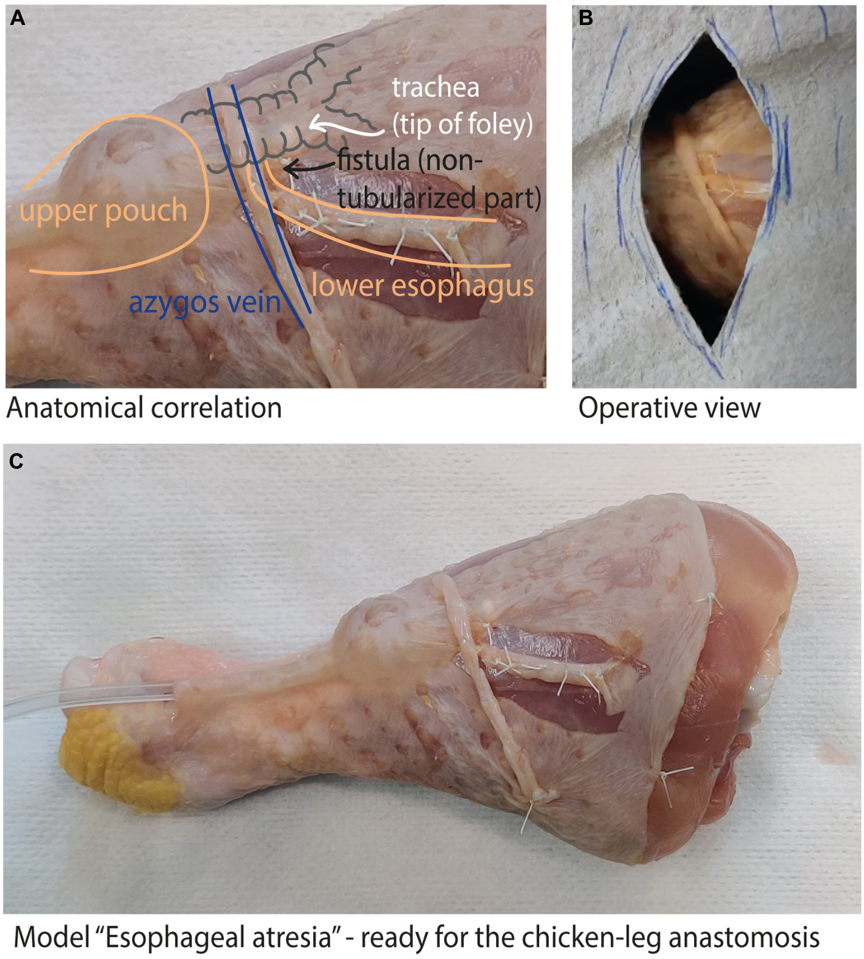

FIGURE 1
Chicken-leg model: **(A)** shows the anatomical correlation of our model with a type C esophageal atresia; **(B)** shows the operative view once the model is completed; **(C)** complete view of the reconfigured chicken-leg skin to create the esophageal atresia model.

TABLE 1 Shopping list.

Amount	Material	Approx. Cost (€)
1	Bio-chicken thigh	1,95
1	***Basic surgical instruments set (1x scissors, 2x forceps, 1x needle-holder, 1xscalpel, 2x mosquito forceps)***	*25*
1	***Foley catheter (8 or 10Fr)***	*2*
1	***Nasogastric feeding tube (6Fr)***	*3*
1	disposable kidney dish	0,05
1	4/0 Vicryl suture (or similar)	0,5
1	6/0 PDS suture (or similar)	8
1	sterile gloves	0,5
Total		41

The materials marked in bold may be reused multiple times, thus reducing the overall cost of the single training session. The cost of such materials amounts to 73% of the total.

instructions video "chicken-leg esophageal atresia - training instructions" (see URL above).

Two independent examiners, one attending surgeon and one fellow trainee, evaluated their surgical skills according to a revised Objective Structured Assessment of Technical Skills (OSATS) (12, 13), based on tissue and instrument handling, knowledge of procedure and procedural flow. On the model of previous simulation-training studies (14, 15),

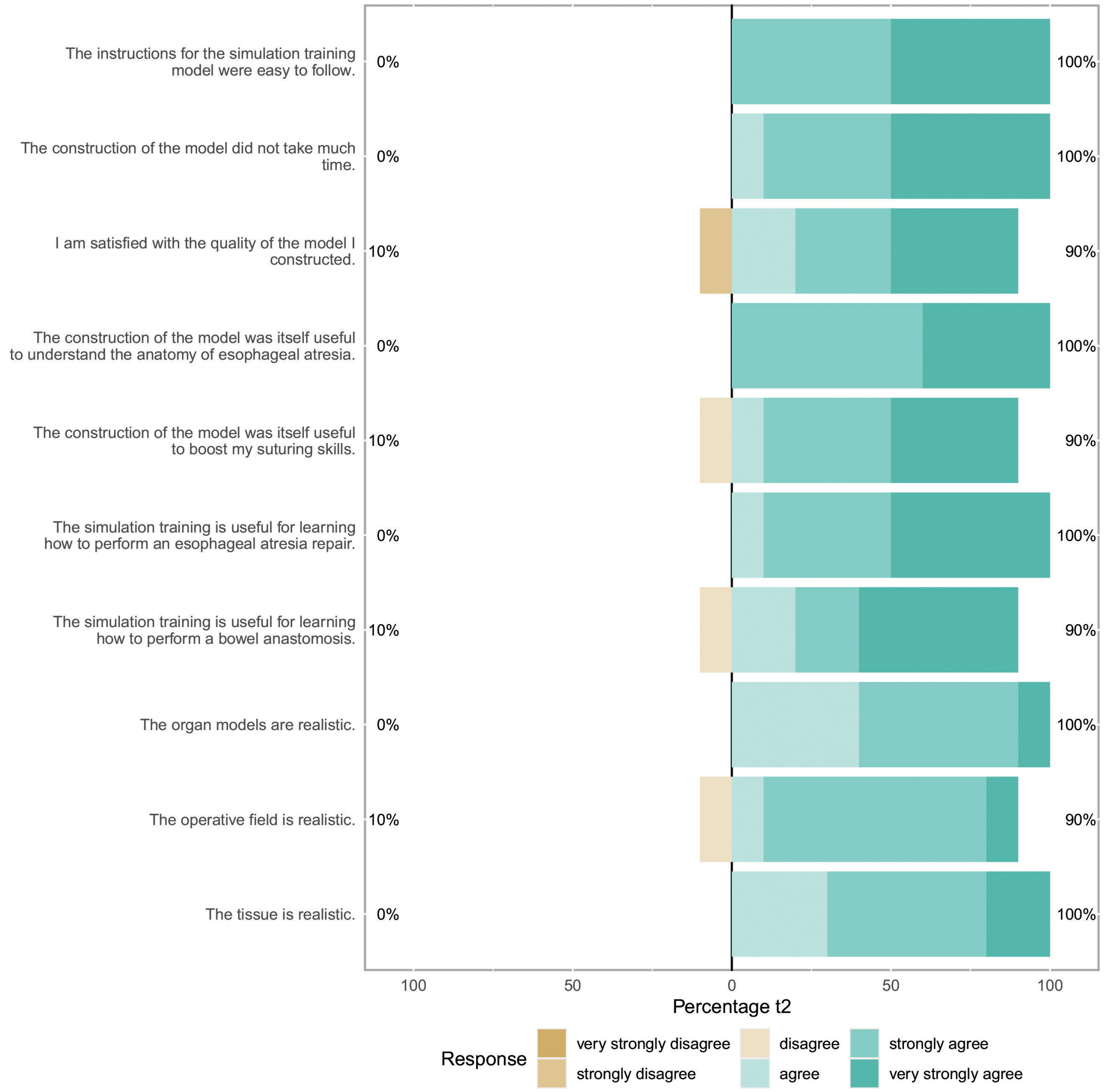

FIGURE 2
Self assessment items: This Likert plot for t2 shows ten self-assessment items concerning the themes of model assembly, self-assessment of skill acquisition and model realism after completion of the whole training. The scales show the respective fractions of participant answers to the questionnaire. Percentages on the left side show total amount of disagreement and percentages on the right side total amount of agreement with the respective item.

an "overall performance" ranking was added which should reflect the overall impression and proficiency in the procedure. Furthermore, specific competences related to esophageal atresia repair such as vena azygos ligation, TEF ligation and anastomosis were closely examined. A detailed description of evaluation criteria can be found in **Supplementary material 3**. The examiners both assessed all datapoints, were blinded to each other's evaluation and to their previous assessments, but not to the phase of the trial itself. After completed assessment of both raters, scores were combined and mean was calculated by a third party. No rater training took place before the study.

Progress between the two sessions was evaluated.

For statistical calculations we used the free statistical software environment R (R Core Team, version 4.1.2 Bird Hippie; The R Project, Vienna, Austria) (16). Plots were drawn using the package ggplot2 (version 3.3.5) (17). Descriptive statistics included mean and confidence interval (CI) for model construction time as well as anastomosis time and size of incision. Evaluation of differences between timepoints t1 and t2 regarding these variables was done using a paired Wilcoxon signed-rank test. Overall performance has been identified as primary endpoint. The self-reported items from the participant questionnaire and the foreign observed items

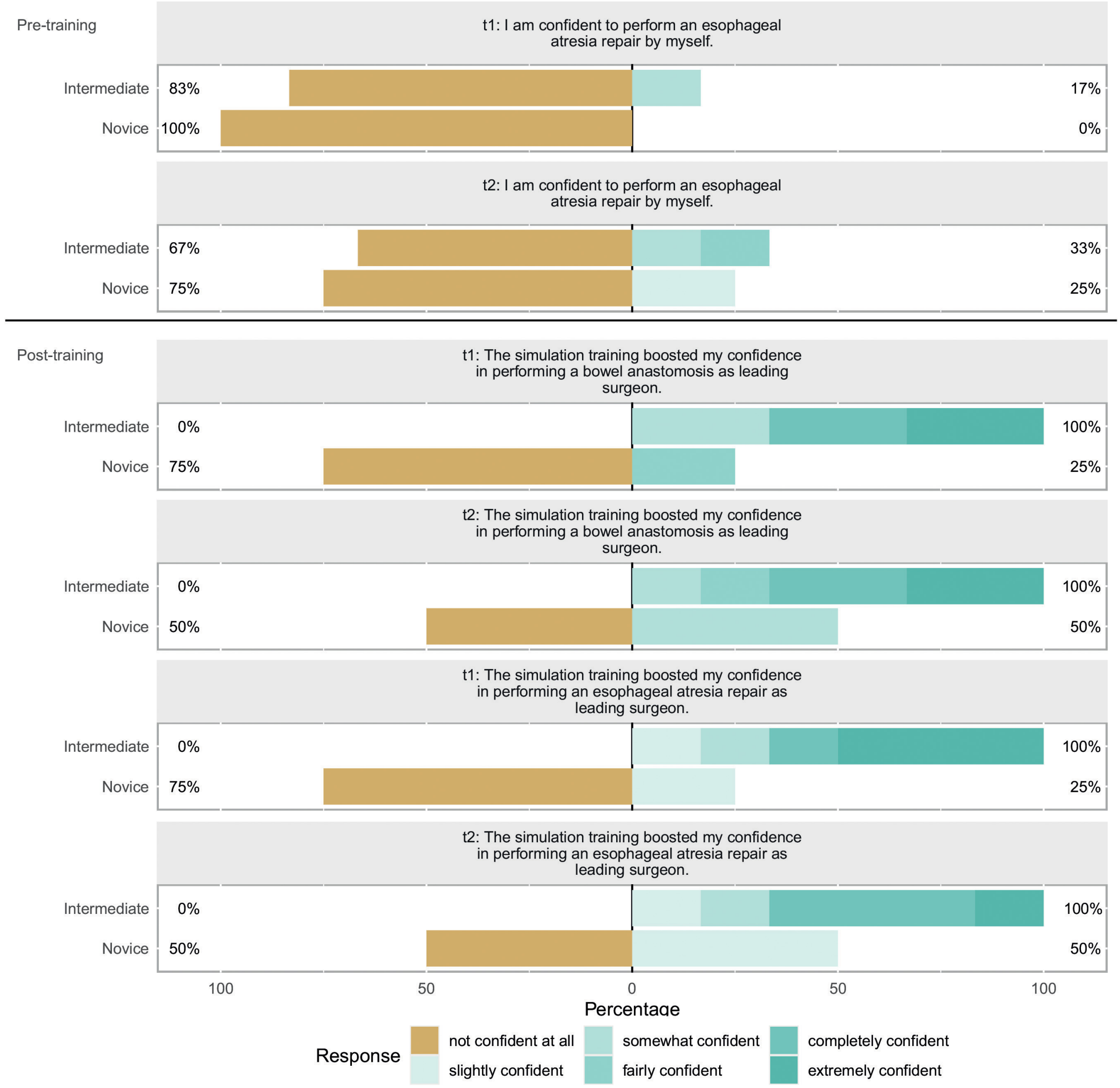

FIGURE 3
Self-reported confidence evaluation: This Likert shows self-reported confidence items for t1 and t2. The scales show the respective fractions of participant answers to the questionnaire. Percentages on the left side show total amount of disagreement and percentages on the right side total amount of agreement with the respective item. In discordance to the other ten items, these items were scored differently with only one item having a distinctly negative connotation. The respective questions are featured above the bars. Bar color represents the given response according to the legend. A subgroup categorization was carried out for this plot. Participants were separated in "Intermediate" and "Novice" depending on their level of training. The cutoff was chosen so both groups were equally large. Q1 was asked before assembly of the model at both timepoints while Q2 and Q3 were both asked after assembly and usage of the model.

from the objective evaluation sheet were described by median as well as interquartile range. Differences between timepoints have been evaluated using the paired Wilcoxon signed-rank test as well. For subjective confidence evaluation pre- and post-training we performed a subgroup analysis and formed two groups based on experience status with a chosen threshold that permitted two equal groups of 5 participants. This resulted in a cutoff at the halfway point of training. Due to the lacking OR experience in esophageal atresia repair we decided to name the two groups "novice" and "intermediate," respectively. For subgroup analysis, testing between groups was carried out using the Wilcoxon rank sum test. The two-sided significance level was $P < 0.05$.

Results

We included 10 participants (8 female, 2 male) for statistical analysis, half of the participants had completed half of their training or had attending status. No participant had already

TABLE 2 Observer variables.

	t1	t2	*z*	*p*
Model construction time (min)	24 [20,28]	19 [16,22]	2.08	0.038
Anastomosis time (min)	35 [28,41]	28 [23,33]	1.94	0.052
Size of incision (cm × cm)	5 [4,6] × 3 [3,4]	4 [4,5] × 4 [3,5]	−1.19	0.234
Tissue handling	3 [2.2,3.8]	4 [3.4,4.6]	−2.34	0.019
Instrument handling	3 [2.8,3.8]	4 [3.4,4.6]	−2.16	0.031
Knowledge of the procedure	3 [2.1,3.9]	4 [3.6,4.4]	−2.04	0.041
Flow	3 [2.2,4.3]	4 [3.8,4.2]	−2.51	0.012
Specific competence: Azygos vein ligation	3 [2.8,3.2]	4 [2.9,4.6]	−1.76	0.078.
Specific competence: TE fistula ligation	3 [2.4,3.6]	4 [2.9,4.6]	−1.97	0.049
Specific competence: Anastomosis	4 [3.5,4.5]	4 [3.1,4.9]	−1.99	0.046
Overall performance	3 [2.4,4.1]	4 [3.4,5.1]	−2.78	0.005

This table contains collected variables by observers during model construction and usage during the first time-point t1 and the second time-point t2. Metric variables featured in the top part of the table have the mean displayed with 95% confidence interval in angular brackets. For ordinal values in the bottom part of the table the displayed value is the median, angular brackets show the 25^{th} and 75^{th} percentile. For testing between the timepoints, a Wilcoxon signed-rank test was performed, *z* denotes the Z-Score and *p* the p-value. Values for the observed variables in the objective evaluation sheet ranged from 1 to 5. With 1 equaling an insufficient performance, 3 featuring a competent display in the respective task and 5 representing a proficient display of skill.

performed an esophageal atresia repair as leading surgeon in the OR. 6 of 10 (60%) had, however, performed at least one bowel anastomosis as leading surgeon. The self-reported items showed no significant change between t1 and t2. **Figure 2** depicts the evaluation of the candidates after having completed the whole training (t2), results for t1 are similar. Results of the subgroup analysis for confidence items at t1 and t2 can be seen in **Figure 3**. A significant boost in confidence is indicated by the Wilcoxon rank-sum test for intermediate participants compared to novice participants. At t1 for confidence in bowel anastomosis intermediate participants reported a median score of 5.5, while novice participants reported a median score of 1, $U = 1$, $z = -2.41$, $p = 0.016$. A similar result can be reported for t2 with a median of 5 for intermediate and a median of 1 for novice participants which resulted in $U = 2$, $z = -2.07$, $p = 0.038$.

For boost in confidence in esophageal atresia repair as a leading surgeon we can report a median score of 5 for intermediate participants and 1.5 for novice participants and the Wilcoxon rank-sum test showing a significant result of $U = 1$, $z = -2.3$, $p = 0.021$. And at t2 median for intermediates was 5 and for novices 2 resulting in $U = 1$, $z = -2.29$, $p = 0.022$.

The objective evaluations regarding time of model-creation, anastomosis, size of incision as well as the OSATS Scores at t1 and t2 are listed in **Table 2**. All observed items, other than the azygos vein ligation, marked a significant improvement amongst participants from one time-point to another. **Figure 4** gives insight on data of the item "Overall performance" in a box plot between timepoints, which shows one of the stronger and more significant improvements over time. This relationship was also examined by means of subgroup analysis as can be seen in **Figure 5**. Model construction time similarly significantly improved from one visit to another. No significant changes could be observed in the size of the incision and time to anastomosis.

Discussion

The American Pediatric Surgical Association (APSA) has recently addressed the issue of *dilution of experience* in pediatric surgery, which currently threatens the quality of children's surgical care (18). Amongst the list of possible solutions, APSA underlined the importance of redefining the paradigm of pediatric surgical training, including in the existing curricula the use of simulators and the organization of simulation-based training (18).

Our initiative derives exactly from the need to reform and adapt the standards of training in our center, to ensure quality of care in the OR, while assuring that graduating residents gain enough experience for future independent practice, with adequate technical skills recuperated outside the operating theater.

We opted to design an easy access low- cost model which could be replicated in any setting, in order to enable its use outside duty hours or mandated didactic sessions as well as in lower-income countries. Simulation models from chicken thighs have been validated in various disciplines like neurosurgery and urology and gained a very high acceptance as, unlike synthetic models, reconfigured chicken skin has the advantage of providing excellent approximation to living tissue (11, 19). To our belief, this offers a notable advantage to the use of plastic materials, which do serve as task trainers but lack in tissue realism. To our knowledge, this is the first chicken-leg model tailored for pediatric surgery training.

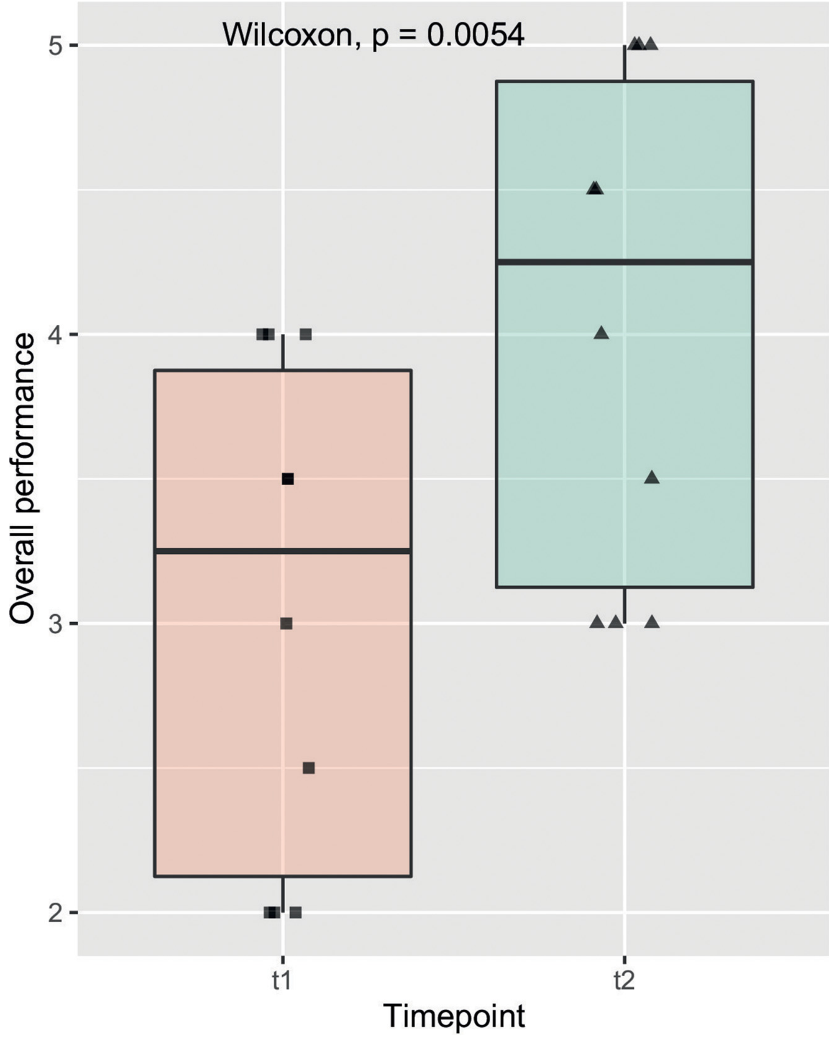

FIGURE 4
Overall performance: The box plot shows the observed item overall performance on the y axis compared to the two timepoints t1 and t2 on the x axis. The solid line represents the median, the box represents the interquartile range (IQR) and the whiskers represent 1.5x IQR. Individual data points are shown on the plot with a horizontal jitter for better recognition. The result of the Wilcoxon signed rank test is featured here as well as in Table 1.

Esophageal atresia is a rare congenital malformation, with an estimated prevalence of 1–2 in 5000 live births. Its adequate repair requires high surgical skills, including the ability to carefully handle delicate tissues in a very small operating space. Being able to perform an esophageal atresia repair independently is a requirement of most pediatric surgery training programs (20). However, due to the low-volume caseload of the disease, also reference centers do not allow residents to acquire enough experience in the clinical setting only.

We therefore considered esophageal atresia repair as a perfect candidate for simulation training and tested the acceptance of our model amongst the trainees and junior attending surgeons in our center.

All participants found the model useful for training in bowel anastomosis and esophageal atresia repair. It is definitely clear, that this training model is not nearly a substitute for performing and training real operations under close supervision, but in particular at the end of the second training all senior residents declared that the simulation had increased their confidence in performing bowel anastomosis and esophageal atresia repair as leading surgeons.

Independently from the level of training, creating the model and performing the repair itself was considered helpful to improve not only the technical skills, but also the basic understanding of the anatomy of the malformation and the steps of the procedure. In case of junior residents in particular, we believe that this aspect may lead to an improvement of the

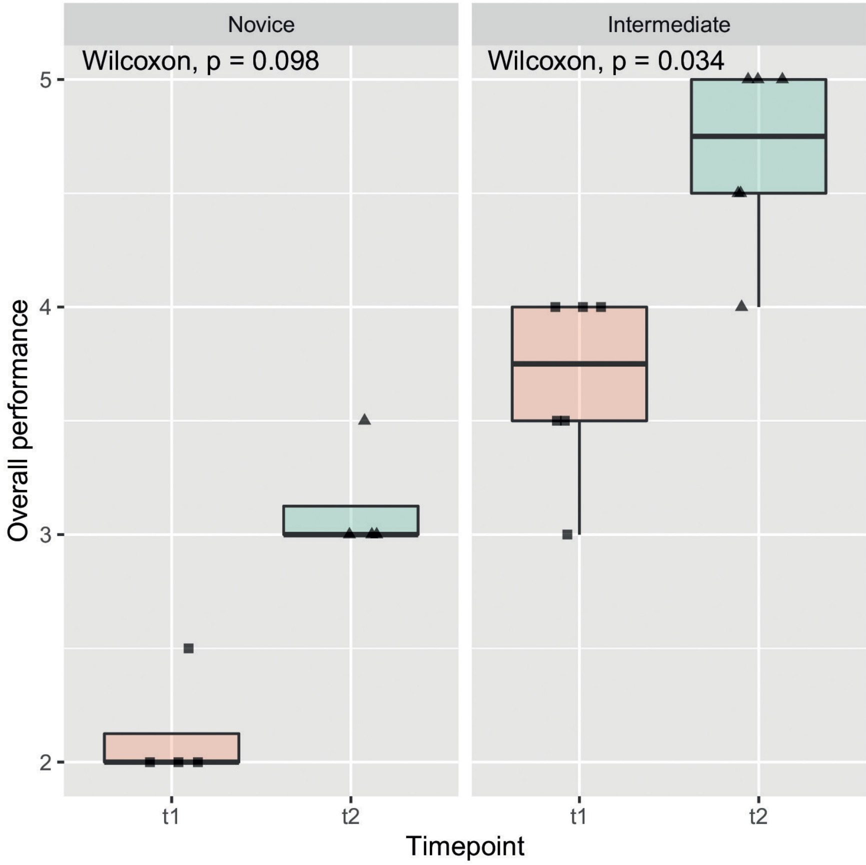

FIGURE 5
Overall performance subgroup analysis: In this box plot, which shows the same data as in this figure, subgroup analysis by experience of participants was performed. Observed increase in overall performance seemed to have been more pronounced in intermediate participants compared to novice participants.

performance in the OR, as it allows the trainees to consciously assist the procedure, without requiring constant guidance.

The model itself was generally favorably accepted by the candidates. It is to be noted, however, that the extensive dissection of the lower pouch, often required to perform the anastomosis on the model, was highlighted as possible flaw. The candidates expressed the concern that this may lead to confusion in the OR, where the lower pouch actually needs to be dissected as little as possible to secure blood supply to the esophagus (21).

It is moreover to be underlined that dissection of the esophageal pouches from the surrounding mediastinal structures may be extremely insidious, and injuries to critical structures such as trachea and vagus nerve are not uncommon. In these regards our model, similarly to those already described in literature, cannot substitute the guidance of an expert surgeon during the actual esophageal atresia repair.

As a task-trainer for dissection, however, it was appreciated especially due to the realism of the tissue. Indeed, the haptic component of the chicken skin was unanimously well appraised, consistently with previous studies on similar models (11). We believe that this constitutes a significant advantage to the synthetic models currently available (1, 5, 22), although the realism of a multilayered tissue is still missing.

Beside the positive subjective evaluation of the candidates, we could also observe an objective improvement of their performances during the two training sessions (t1 vs. t2) (**Figures 4**, 5). Indeed, at t2 all candidates performed the repair in less time and scored higher in the OSATS. A statistically significant improvement was detected in the "intermediate" group, underlining that this training may be particularly helpful for candidates that have already gathered some experience in bowel anastomosis or in assisting an esophageal atresia repair. This correlates well with the traditional assumption that surgical expertise is linked to surgical volume (23). Simulation training offers in this context the advantage of a safe environment and reproducible conditions, which also allows to tailor the frequency of simulation to the needs of the single trainee.

We believe that a central advantage of our model is that the candidates are required to perform the whole procedure with minimal to none guidance, being forced to think like expert surgeons. The acquisition of surgical expertise is indeed not limited by single motor skills, but calls for a broader intellectual practice (24). The always more intensive involvement of attending surgeons in the OR notably hampers the acquisition of independent decision-making, with the risk of retaining the trainees at the level of technicians.

Although promising, our preliminary study has a number of limitations. Validation study of the model by a panel of experts is lacking. Moreover a larger pool of candidates, ideally from different training programs and training levels, would be required to further confirm our preliminary data on the positive effect of the training on surgical skills. External evaluation would also be needed to refine the impartiality of the objective evaluation. Indeed, as underlined by other single-center training studies (25) the fact that the examiners already knew the candidates may have biased their judgment.

The decision to include a peer assessment has been inspired by recent literature (26–28), which indicates that there is good agreement between novice and expert raters and that actually expertise in performing a given procedure is not a prerequisite to assess it. However, as this is still matter of debate (29), it needs to be considered as possible further limitation of the study.

Further studies are required to evaluate the model also for minimal-invasive repair.

Conclusion

Implementing simulation training programs to the classical curriculum of pediatric surgical training is nowadays necessary to allow graduating residents to meet the required level of surgical skills as a basis for a more effective expert training in the OR. Our easy access low-cost simulation model represents a feasible and tissue realistic option to increase surgical performance outside the OR.

Data availability statement

The original contributions presented in the study are included in the article/**Supplementary material**, further inquiries can be directed to the corresponding author.

Author contributions

WK and FP: study conception and design and acquisition of data. FP, PS, and WK: analysis and interpretation of data and drafting of the manuscript. MM, WK, EH, and PS: critical revision of the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The reviewer KS declared a shared affiliation with the authors to the handling editor at the time of review.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fped.2022.893639/full#supplementary-material

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Teaching fiberoptic-assisted tracheoscopy in very low birth weight infants: A randomized controlled simulator study

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Objective: We developed a fiberoptic-assisted tracheoscopy (FAST) method to avoid direct laryngoscopy during surfactant replacement therapy and compared two training approaches on a very low birth weight (VLBW) infant simulator.

Design: This prospective randomized controlled study was conducted at the Department of Neonatology and Pediatric Intensive Care Medicine of the University Medical Center Hamburg-Eppendorf, Germany.

Participants: We recruited physicians, trainees, students, and nurses without prior experience in endoscopic techniques.

Interventions: Participants were assigned randomly to a group that received instructions according to Peyton's Four-Step Approach and a control group that received standard bedside teaching only.

Main outcome measures: Primary endpoints were the total and the component times required to place the bronchoscope and the method success.

Results: We recruited 186 participants. Compared with the control group, the Peyton group had a lower mean (±standard deviation) FAST completion time (33.2 ± 27.5 s vs. 79.5 ± 47.9 s, $p < 0.001$; $d = 1.12$) and a higher FAST success rate (95% vs. 84%, $p = 0.036$, $V = 0.18$).

Conclusion: After standardized training, the vast majority of novices completed FAST successfully. Peyton's four-step approach resulted in faster and more successful performance than standardized training.

KEYWORDS

medical education, Peyton's four-step approach, premature infant, surfactant replacement therapy, bronchoscopy

Introduction

There has been a recent growth in alternative surfactant administration methods for preterm infants in respiratory distress. The standard method involves laryngoscopy-guided endotracheal placement of a thin catheter, expected to be narrower than a standard endotracheal tube during spontaneous breathing under continuous positive airway pressure (1–4). Less-invasive surfactant administration (LISA) has been shown to potentially reduce ventilation duration and has been suggested to improve outcomes in very low birth weight (VLBW) infants (1, 5, 6). A recent meta-analysis concludes that administration of surfactant *via* thin catheter compared with the administration *via* an endotracheal tube is associated with reduced risk of death or bronchopulmonary dysplasia (BPD), less intubation in the first 72 h, and reduced incidence of major complications and in-hospital mortality (1). LISA appears to be promising and feasible, and has been adopted in numerous locations around the world (7–11). However, whereas there is consensus about the necessity of analgesia and sedation in premature infants undergoing laryngoscopy for intubation (12), there are no standard analgesia and sedation recommendations for LISA. While medication has been reported to improve patient comfort during LISA (13), drug-associated side effects such as hypopnea or apnea, have been reported to reduce the LISA success rate (12). Weighing the benefits of a successful LISA against infant pain exposure, many operators choose not to administer medication for laryngoscopy (10).

No studies have been published on fiberoptic-assisted surfactant administration in VLBW infants. The use of flexible bronchoscopy for difficult airways is becoming a standard of care in many pediatric intensive care units around Europe and the United States. Furthermore, in light of the availability of increasingly smaller bronchoscopes and the search for alternative methods to administer surfactant, flexible bronchoscopy will probably soon find its way into the clinical care of infants with VLBW.

We developed a fiberoptic-assisted tracheoscopy (FAST) method. During FAST, a thin, flexible bronchoscope with a working channel is placed in the proximal trachea without direct laryngoscopy. Here, we tested whether FAST can be learned and applied by novice providers within a realistic time frame. We taught the method *via* two different teaching concepts with a high-fidelity VLBW infant airway simulator. The primary endpoints were FAST success and the time required to place a bronchoscope in the proximal trachea. Participants performed the task directly after this bedside teaching instructional session. Peyton group participants went through the above additional four-step instruction (14).

Materials and methods

Study design

This prospective study was conducted at the Department of Neonatology and Pediatric Intensive Care Medicine of the University Medical Center Hamburg-Eppendorf, Germany, from January to August 2021, under a waiver from the local ethics committee (EK-15/02/2021). We recruited physicians, trainees, students, and nurses to participate. Informed consent was obtained from institutional staff councils and the participants. Each participant completed an intake questionnaire regarding prior intubation experience, endoscope equipment knowledge, professional specialization, and training level. We excluded three participants with previous endoscopy or bronchoscopy experience. A randomization list was used to divide the participants into a Peyton (intervention) group, taught by Peyton's four-Step Approach (15), and a control group, given standard bedside teaching (14) (BS, MW, and VV). Peyton's instructions included: (1) instructor *demonstration* at usual speed without commenting; (2) *deconstruction* wherein an instructor performs the task slowly and comments on each step; (3) *comprehension* wherein the trainee describes each step with instructor feedback as needed; and (4) independent trainee *performance* under instructor supervision.

Instructional sessions were conducted in small groups (≤5 participants), including standardized instruction on the flexible bronchoscope and the following procedure steps: (a) oral insertion of the bronchoscope; (b) visualization of the vocal cords; and (c) controlled passage of the vocal cords into the proximal trachea. Participants were then allowed to familiarize themselves with the bronchoscope for 120 s. The instructional sessions were scheduled for 15 min for both Peyton and the control group. The timing was started when the bronchoscope tip passed the lips and stopped when it reached the proximal trachea (t_{FAST}) or 180 s had elapsed. A t_{FAST} longer than 180 s was considered a FAST failure. Two intermediate times were assessed: from procedure start to vocal cord visualization (t_{vc}); and from t_{vc} to bronchoscope placement in the proximal trachea (t_{TR}). The video was recorded *via* the bronchoscope. The subjects completed a second questionnaire. The primary endpoints were procedure success and the time required for FAST (t_{FAST}). The secondary endpoints were possible failure causes and participants' self-assessment. Immediately after completion, participants were asked with a questionnaire how difficult they found it to learn FAST and how confident they would feel performing it.

We used the VLBW infant airway simulator AirwayPaul (SimCharacters©, Vienna, Austria), which models an infant of 27 + 3 weeks gestational age (1,000 g) with excellent airway anatomic and functional fidelity (16). The experimental setup is shown in **Figure 1**. **Figure 2** shows the route of the flexible

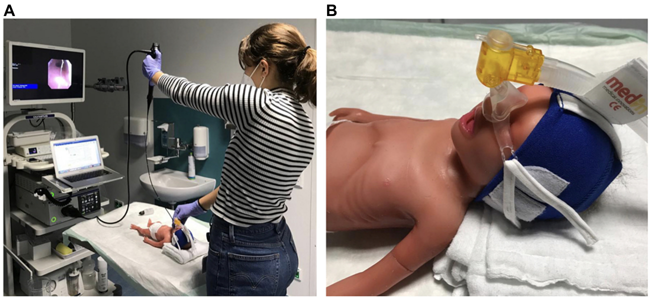

FIGURE 1
Experimental setup. **(A)** The simulator was positioned on a height-adjustable table in front of the bronchoscopy tower with the head towards the participant. Participants used a 3.1-mm-diameter Olympus EvisExera III digital video bronchoscope (BF-XP190 2711037, Tokyo, Japan) with a 1.2-mm working channel and a CV-190 video processor and xenon light source. Bronchoscope insertion was facilitated with lubricating gel. **(B)** VLBW infant simulator positioning with the head slightly elevated on a pad to optimize the view for tracheoscopy. A continuous positive airway pressure device (Fisher andPaykel, Schorndorf, Germany) was placed on the nose to simulate respiratory support during stabilization in the delivery room.

video bronchoscope through the airway of the VLBW-infant simulator.

Statistical analysis

A required minimum sample size of N = 89 participants per group was calculated assuming a mean t_{FAST} delta of 20 s and a standard deviation of 40 s between groups with a specified power of 0.9 and a significance level of 0.05. The random allocation sequence was generated using the sample function in R with a 50% probability (PD). Continuous and categorical variables are reported as means ± standard deviations and as category counts and percentages, respectively. Continuous variables were compared with two-sided t-tests, and effects were reported as Cohen's D effect sizes. A log transformation was applied to parameters with right-skewed distributions to increase the stability of the t-test. Discrete data were compared between groups with the Chi-square test and effects reported as Cramer's V effect sizes (17). We reported effect sizes to facilitate the interpretation of the importance of the results (17, 18). The P-values less than 0.05 were considered significant. Statistical analyses were performed in R 4.1.1 (R Core Team, Vienna, Austria).

Results

Participants

The characteristics of each group's participants, including prior pediatric airway management skills, are summarized in **Table 1**. All the participants (N = 186) completed their assigned training and were analyzed for the primary outcome. The **Supplementary figure 1** shows participant recruitment and analyses performed in each group.

Fiberoptic-assisted tracheoscopy time

The mean t_{FAST} with the VLBW manikin was significantly shorter in the Peyton group (33.2 ± 27.5 s) than in the control group [79.5 ± 47.9, p < 0.001; confidence interval (CI), 0.63–1.11; d = 1.12] (**Figure 3**). Similar differences were observed for the intermediate times t_{VC} (Peyton 19.4 ± 18.9 s vs. controls 54.1 ± 40.9 s, p < 0.001; CI, 0.73–1.26; d = 1.11) and t_{TR} (Peyton 14.7 ± 20.1 s vs. controls 29.0 ± 33.1 s, p = 0.002; CI, 0.01–0.90, d = 0.39). **Figure 4** shows the t_{FAST} for the Peyton group and the controls separately according to the respective professional status of the participants. Again, participants of all subgroups performed better when instructed according to the Peyton's approach.

Success rate

The FAST success rate was significantly higher in the Peyton group (95%) than in the control group (84%, p = 0.036, V = 0.18) (**Figure 5**). The most common causes for FAST failure in the control group were malpositioning in the esophagus, bronchoscope-handling difficulties, and lack of orientation within the airway. In the Peyton group, malpositioning in the esophagus did not occur, and other failure causes were much less frequent than in the control group (**Table 2**).

Post-participation survey

Whereas 96% of Peyton group participants found FAST easy to learn, only 87% of control group did so (**Figure 6**).

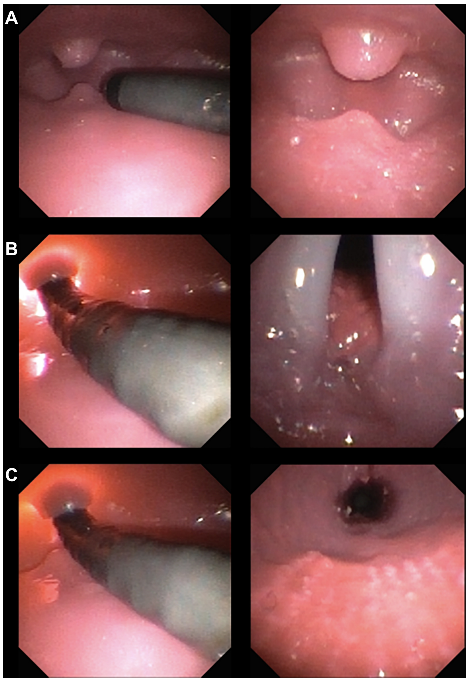

FIGURE 2
Flexible video bronchoscope route through the airway of a VLBW-infant simulator.The left side shows the lateral view of the bronchoscope, the right side the view through the bronchoscope. **(A)** The bronchoscope enters the mouth with the uvula and epiglottis visible at the "bottom" and "top", respectively. **(B)** The bronchoscope is angulated behind the epiglottis until the larynx comes into sight. **(C)** Finally, the bronchoscope is inserted through the glottis into the trachea.

TABLE 1 Participant characteristics.

Characteristic	Control N = 93		Peyton N = 93	
Dominant hand				
Right	85	(91.4)	87	(93.5)
Left	7	(7.5)	5	(5.4)
No specification	1	(1.1)	1	(1.1)
Professional specialty				
Student	66	(71.0)	58	(62.4)
Pediatrics	21	(22.6)	27	(29.0)
Adult medicine	6	(6.5)	8	(8.6)
Professional status				
Chief physician	–	–	1	(1.1)
Consultant	7	(7.5)	6	(6.5)
Fellow	15	(16.1)	16	(17.2)
Resident	26	(28.0)	26	(28.0)
Student	37	(39.8)	36	(38.7)
Nurse	8	(8.6)	8	(8.6)
Assisted or watched the following procedure				
Laryngoscopy	33	(35.5)	38	(40.9)
Intubation child	24	(25.8)	27	(29.0)
Intubation term infant	20	(21.5)	20	(21.5)
Intubation premature infant	17	(18.3)	17	(18.3)

Data are N (percentage).

Conversely, 36% of control group participants indicated they were not confident with performing FAST again, while only 13% of Peyton group participants reported being unconfident.

Discussion

This randomized controlled study demonstrated that FAST *via* a thin, flexible bronchoscope may be a feasible approach for LISA in a high-fidelity VLBW infant simulator. Most novice participants performed the procedure successfully after training with participants instructed with Peyton's four-step approach showing better performance than controls.

Our finding that participants who were taught by Peyton's approach placed the bronchoscope more quickly than participants that received only bedside teaching is in line with Krautter et al.'s results for gastric tube placement in indicating that the Peyton method is highly effective for teaching complex medical skills (14). Its main distinction from bedside teaching in the comprehension step (19) which emphasizes reflection as a crucial processing step during learning (20), provides an opportunity to correct mistakes immediately (21), and promotes long-term retention (22, 23). The graphical representation of tFAST times by professional status (**Figure 4**) also showed a better performance of those participants who had been instructed according to the Peyton approach, which supports the superiority of this teaching approach in the context of FAST. The time required for the Peyton approach in our study setting was similar to the time for bedside teaching, although we did not document these times precisely for each participant. However, the duration of the instructional sessions never exceeded 15 min in either case.

Fiberoptic-assisted tracheoscopy success rate and post-participation survey

Video analysis revealed several causes for FAST failure (**Table 2**), including misplacement in the esophagus (12.9%) and poor orientation (9.7%), likely due to inadequate anatomical understanding of the VLBW airway (24, 25). The vast majority of participants trained using Peyton's four-step approach found FAST easy to learn and felt confident or very confident with performing FAST again (**Figure 6**). We postulate that the stepwise demonstration as part of the Peyton approach may explain the participants' better spatial and anatomical orientation when performing FAST.

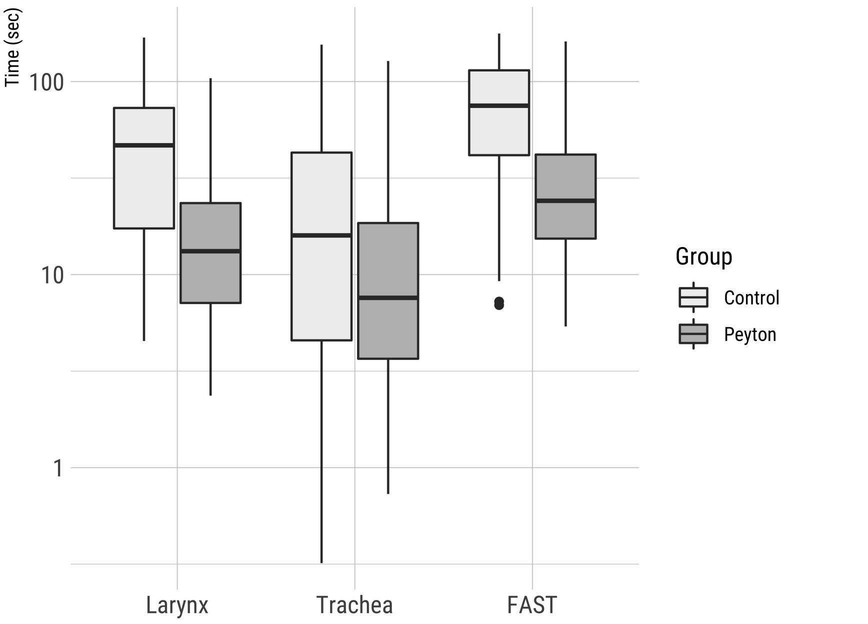

FIGURE 3
Total time for successful FAST completion on a logarithmic scale. Intermediate times for visualization of the larynx and the time elapsed between larynx visualization and endotracheal bronchoscope placement are shown.

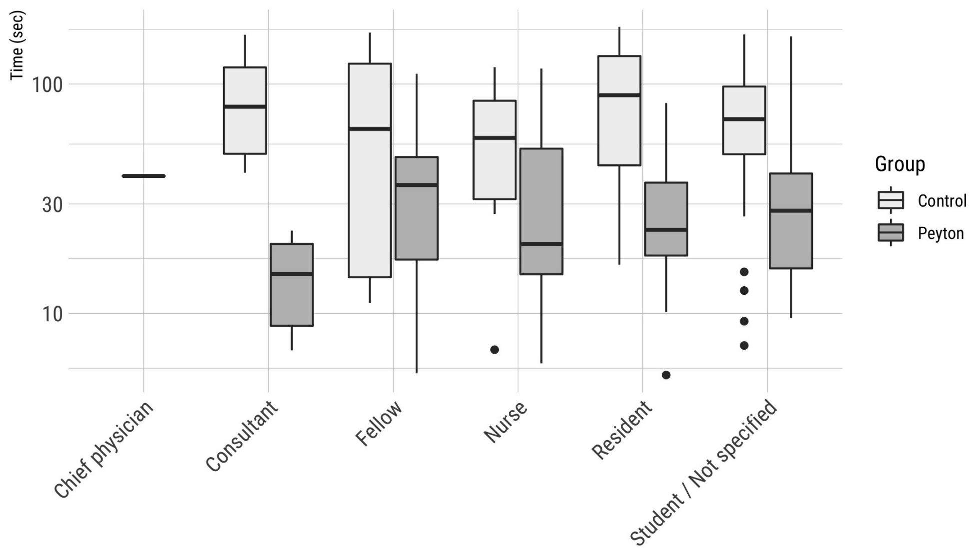

FIGURE 4
Fiberoptic-assisted tracheoscopy times according to the participants' professional status and group.

Fiberoptic-assisted tracheoscopy and surfactant replacement therapy

FAST is a modified tracheoscopy with a flexible bronchoscope that represents the first crucial step toward a clinical method for fiberoptic-assisted surfactant administration in infants with VLBW. The surfactant could be administered under visualization in infants with VLBW with respiratory distress syndrome *via* the bronchoscope's working channel. LISA is a complex technique to learn wherein an intra-tracheal catheter is placed under direct laryngoscopy to administer surfactant during spontaneous breathing (1–3, 26, 27). Even experienced clinicians may need multiple attempts to complete it correctly (28). Bronchoscopy is

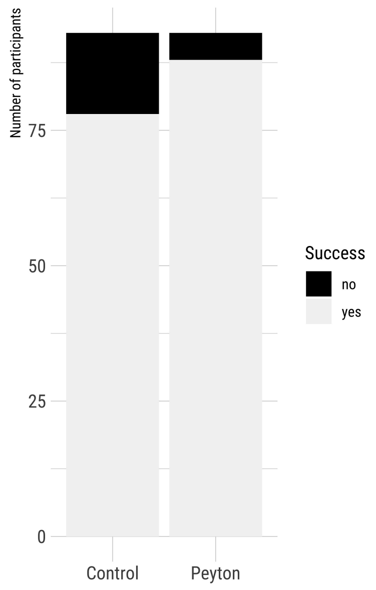

FIGURE 5
Fiberoptic-assisted tracheoscopy procedure success rate according to the group.

TABLE 2 FAST failure causes by group.

Cause	Control $N = 93$	Peyton $N = 93$
Malpositioning in the esophagus	12 (12.9)	0 (0)
Difficulties handling the bronchoscope	10 (10.8)	4 (4.3)
Lack of orientation	9 (9.7)	2 (2.2)
Wrong timing of kinking of the bronchoscope	7 (7.5)	4 (4.3)
Difficulty passing vocal cord level	3 (3.2)	2 (2.2)

Data are N (percentage).

commonly employed in pediatric pneumology and intensive care medicine (29, 30). Although profound (or general) analgesia is standard for pediatric bronchoscopies (30), supraglottic airway inspection with a flexible bronchoscope is feasible and safe without sedation (31, 32). We chose 180 s as the cut-off for FAST completion because preterm infants do not tolerate long and stressful procedures in the critical situation of respiratory distress. It remains unclear how taxing FAST would be for actual preterm infants. The first part of the FAST procedure, including passage of the mouth until vocal cord visualization (tVC) would probably be uncomfortable but not to be compared with the intensity and the potential pain stimulus of a laryngoscopy. During this first part of FAST (tVC), which accounted for 58% (Peyton) and 68% (Controls) of the total FAST time, relatively unimpaired spontaneous breathing might be possible. The crucial burden of FAST would be the last part with the obstruction of the trachea after the passage of the vocal cords. The relatively large diameter of the bronchoscope used for FAST (approximately the diameter of a 2.0 tube) may impair spontaneous breathing because the larynx is substantially blocked. This obstruction of the trachea by the endoscope at the moment of vocal fold passage could therefore be a relevant limitation of FAST during clinical implementation in actual preterm infants. More stable and larger preterm infants could probably tolerate FAST better than lighter and unstable patients. Surfactant administration following FAST resembles the intubation surfactant extubation (INSURE) method but does not require direct laryngoscopy and potentially obviates systemic anesthesia. Respiratory stability, hemodynamic stability, pain response, and efficacy have yet to be compared between LISA, INSURE, and FAST.

Limitations

First, subjects and instructors were not blinded. Nevertheless, behavioral criteria were adhered to strictly during instruction. Second, participants' laryngoscopy skills were not evaluated before inclusion into the study. As we did not re-evaluate the participants' FAST performance, we cannot provide data regarding their long-term learning success. Thus, although the anatomical and functional fidelity of the simulator has been graded by experts as highly realistic, these results are not transferable to VLBW infants without limitations. For technical reasons, the surfactant was not administered directly into the simulator, limiting conclusiveness concerning surfactant administration. We used a VLBW airway simulator, which resembles an infant with approximately 1,000 g birth weight. Whether FAST would be possible in even lighter infants with smaller airways remains unclear. Even high-fidelity simulators cannot adequately reproduce the conditions encountered in actual patients. The major problems faced at the bedside of a living child are the child's activity, breathing, tone, and stability. In addition, successful visualization and placement in a living infants' larynx may require significantly more clinical training with the flexible bronchoscope. In addition, this study cannot answer whether the duration of FAST would be similar in actual patients and whether patients would clinically tolerate the manipulation with a relatively rigid bronchoscope in the mouth, pharynx, and upper airway. As the surfactant administration *via* a bronchoscope was never done in extremely preterm infants, comparisons with clinically proven administration techniques should be evaluated in future clinical studies.

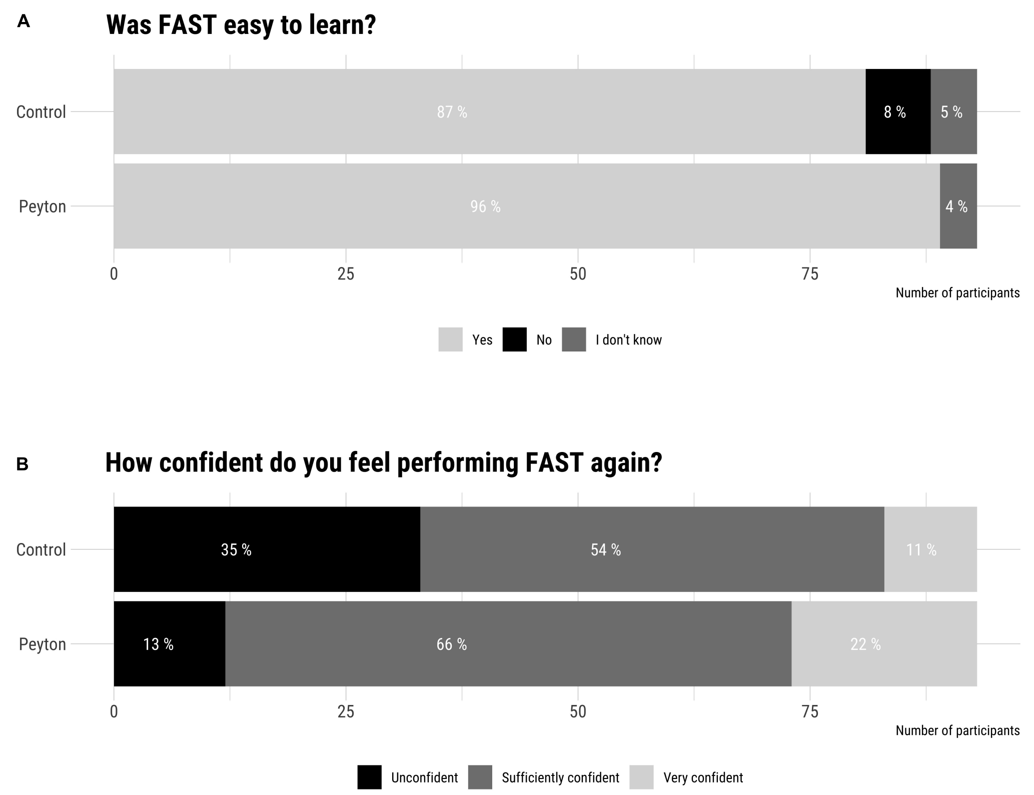

FIGURE 6
Post-participation survey results. Difficulty learning **(A)** and self-confidence to perform **(B)** Fiberoptic-assisted tracheoscopy (FAST).

Conclusion

We conclude that FAST can be taught to novices readily on highly realistic VLBW infant airway simulators, with the Peyton method enhancing success rate and task speed relative to standard bedside training. FAST is the first crucial step toward a clinical method for fiberoptic-assisted surfactant administration in infants with VLBW with the potential advantage of reducing invasiveness compared to methods requiring direct laryngoscopy.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethics review and approval was not required as per local legislation and institutional requirements. The participants provided written informed consent to participate in this study.

Author contributions

MW and PD designed the study, analyzed the data, critically discussed the results, and wrote the first draft of the manuscript. LS, PM-K, CE, and DS advised on the study design, helped discuss the results, and revised the manuscript critically for important intellectual content. BS and VV collected the data. EV advised on the statistical analysis. All authors contributed to the article and approved the submitted version.

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Conflict of interest

PD worked as a simulation instructor for SimCharacters (Vienna, Austria) from 2010 to 2013.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fped.2022.956920/full#supplementary-material

SUPPLEMENTARY FIGURE 1
Overview of participant recruitment and analyses performed in each group.

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Avatar and distance simulation as a learning tool – virtual simulation technology as a facilitator or barrier? A questionnaire-based study on behalf of Netzwerk Kindersimulation e.V.

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Background: Virtual simulation modalities have been implemented widely since the onset of the severe acute respiratory syndrome coronavirus 2 pandemic restrictions in March 2020, as educators face persistent restrictions to face-to-face education of medical students and healthcare professionals.

There is paucity of published data regarding the benefits and barriers of distance and avatar simulation training modalities.

Methods: Following a 2-day virtual pediatric simulation competition facilitated by Netzwerk Kindersimulation e.V., using remote human avatars and distance simulation, we conducted a multicenter survey to explore the advantages and challenges of avatar and distance simulation among participants. We used a modified Delphi approach to draft and develop the 32-item online questionnaire with 7-point Likert-like scales (7 being the highest rating).

Results: Twenty participants answered our questionnaire. Respondents indicated both a high overall satisfaction (median of 5.0 [Q25–Q75: 4.0–6.0]) for avatar and distance simulation 6.0 (5.0–6.0), respectively, as well as a high achieved psychological safety with both simulation types (5.0 [4.0–6.0] vs. 5.0 [4.0–6.0]). The most frequently reported profits of avatar and distance simulation included the elimination of travel distances, associated lower costs, less time spent attending the education activity, and effective communication and leadership training, especially with avatar simulation. Most often named challenges were technical problems, limited reception of non-verbal cues and a spatial distance from the team/educator.

Abbreviations
COVID-19, coronavirus disease 2019; F2F, face-to-face; GNPI, German society for neonatal and pediatric intensive care medicine; SBE, simulation-based education; VR, virtual reality.

Discussion: Based on the results of this pilot study, avatar and distance simulation can be employed successfully and appear to be good supplements to face-to-face simulation. Other studies are warranted to further explore the effectiveness of various types of virtual simulation compared to conventional presential simulation. We suggest using avatar-based simulation for targeted communication and leadership skills training and the application of distance simulation to bring simulation experts virtually to remote places where educator resources are lacking.

KEYWORDS

simulation-based education, avatar simulation, distance simulation, virtual simulation, advantages, challenges, pediatric acute care

Background

Since March 2020, the ongoing pandemic caused by the severe acute respiratory syndrome coronavirus 2 has persistently put restrictions on simulation-based education (SBE) and training (1, 2). Simulation educators have turned to virtual, remote or hybrid training modalities to compensate for reduced exposure to simulated pediatric emergencies in places where traditional education had to be limited or cancelled.

The effectiveness of face-to-face (F2F) (also referred to as presential) SBE as a learning tool in healthcare has been widely described (3), with significant effects on knowledge, process skills, product skills, time skills and patient outcomes (4). However, only scant data are describing whether this powerful effect can also be achieved through virtual, remote or telesimulation modalities (5–8). There is a knowledge gap regarding the benefits and barriers of distance simulation (term used hereafter for reasons of clarity, but not excluding remote or telemedicine simulation modalities, unless the authors specifically refer to one of the other terms) and avatar simulation training modalities, with only limited published evidence (6, 9).

These terms are partly overlapping and interchangeable and have been defined as follows: Virtual simulation "… is where a real person operates simulated systems", which may utilize avatars, i.e., virtual objects "used to represent a physical object (e.g., a human) in a virtual world" (10). Distance simulation refers to "implementing a simulation or training at a physical distance from the participant(s)", while remote simulation is "… performed with either the facilitator, learners, or both in an offsite location separate from other members to complete educational or assessment activities" (10). For this purpose telesimulation may be used, which utilizes telecommunication and simulation resources to "provide education, training, and assessment to learners at an offsite location" (5).

More challenging aspects regarding avatar and virtual reality (VR) simulation, defined as "a computer-generated three-dimensional environment that gives an immersion effect" (10), include high purchase costs, physical side effects like visual asthenopia and motion sickness, and possible psychological side effects such as dissociation (11, 12).

Although distance simulation allowed simulation activities to continue while maintaining social distancing requirements, adaption to these circumstances differed between geographic regions with an Anglo-American/Anglo-Saxon and Indian vs. European preponderance regarding non-presential training modes (13). As the pandemic of the coronavirus disease 2019 (COVID-19) will continue to hinder F2F SBE and training, medical schools and teaching hospitals will have to continuously adapt and modify their educational activities to provide essential simulation training. While presential SBE will and shall not be replaced due to its proven benefits, understanding the benefits and barriers of distance simulation will help clinical educators and simulation trainers plan and deliver SBE during these challenging times.

Aim of the study

We sought to explore potential advantages and obstacles with two different simulation training modalities (avatar and distance simulation) over conventional presential SBE among European simulation competition participants represented in our pediatric simulation network "Netzwerk Kindersimulation e.V." (14). We hypothesized that there would be distinct but specific advantages with either modality compared to standard SBE that will be useful to know for educators and simulation trainers even for future SBE beyond the COVID-19 pandemic.

Materials and methods

Ethics

The Institutional Review Board at Karolinska University Hospital, Stockholm, Sweden (File number 2021 02983, June 29, 2021) waived the need for ethics approval. Participation in the survey was voluntary, and participation in the survey was considered "consent by participation". We used ID numbers to code participants and requested no directly identifying data. We stored data in a secure repository accessible to the investigators only. As far as applicable, all procedures from this investigation followed the Helsinki Declaration (15). All researchers complied with the Data Protection Acts of their respective academic institutions.

Study design and setting

We performed an international, prospective study using an online survey in the German language (**Supplementary File 1**: Participant evaluation virtual simulation competition survey in German). We translated the original survey to the English language for the purpose of publication (**Supplementary File 2**: Participant evaluation virtual simulation competition survey in English).

Procedure

Simulation competition

We performed a 2-day virtual pediatric simulation competition (June 15–16, 2021) during the German Society for Neonatal and Pediatric Intensive Care Medicine (GNPI) 2021 annual conference (16), which was held virtually due to the third COVID-19 wave. In the virtual simulation competition, we enrolled four German-speaking teams from pediatrics, pediatric intensive care, and pediatric emergency medicine. Each team was composed of three specialists in training, one pediatric nurse and one specialist physician ($n = 5$).

For the qualification rounds, we performed avatar simulations using the Zoom® platform (Zoom Video Communications, San Jose, California, United States) (**Figure 1**). An exclusive Zoom® meeting link was provided to the four participating teams, avatars, jurors (RML, Sweden, and one juror from each Switzerland and Germany) and the technician for the qualification round. The avatar simulations employed an avatar team of one nurse and two doctors as well as a technician physically located at St. Josef's Hospital in Vienna, Austria, performing an in-situ simulation scenario. The four participating teams were located remotely in Germany ($n = 1$, Münster) and Austria (Vienna $n = 2$, Eisenstadt $n = 1$). The avatars acted according to orders from the remotely participating teams, which were transmitted as voices into the room, in a simulation scenario with a pediatric emergency topic (supraventricular tachycardia).

During the finals, distance simulation was featured (**Figure 2**). We again used the Zoom® platform (Zoom Video Communications, San Jose, California, United States), and exclusive links were sent to the four participating teams, jurors, the technician for the final round and 12 registered passive spectators. All teams were challenged by two pediatric emergency simulation scenarios (drowning case for teams 1 and 2, status epilepticus case for teams 3 and 4). In this distance simulation, each team performed at their home institution, whether at the local simulation center (Münster) or *in situ* at the home hospitals (Comprehensive Center for Pediatrics, Medical University of Vienna; St. Josef's Hospital, Vienna; Hospital of the Brothers of Saint John of God, Eisenstadt) as per participant choice. For the distance simulation, the team's senior doctor acted as a confederate [defined as "an individual(s) who, during the clinical scenario, provides assistance locating and troubleshooting equipment" (10)]. The confederates received and accessed the scenario the day before the competition to (i) prepare the simulation manikin and training setting and (ii) operate the scenario for the competition according to the detailed script.

The virtual jury and organizing committee took part in the Zoom® competition to ultimately choose the winner by assessing medical and teamwork aspects. A specific 60-point evaluation tool was used for each scenario (**Supplementary Files 3A–C**). Teams could achieve a maximum of 60 points with each scenario for various medical actions (e.g., adherence to treatment algorithms according to European Resuscitation Council (17) and team behavior, including crisis resource management principles (18), team reflections (19), STOP sequences, "10 s for 10 min" (18) and effective communication strategies such as "closed-loop" communication (20, 21). The tool was based on evaluation tools used for previous simulation competitions (personal communication RML) and adapted after current evaluation tools for the team behavior part (22). The team with the highest number of points achieved in the final scenario was named the winner. The jurors had prepared a pediatric resuscitation guideline quiz in case two teams had the same number of points to appoint the winning team, which was ultimately to be presented for educational purposes only. For all three simulated cases, the organizing committee (RML, one pediatric expert from Switzerland, Austria, and Germany) and jurors performed a short medical debriefing for all participating teams and the audience. Teamwork aspects were debriefed in a separate virtual debriefing session with each team and without an audience the day after the competition to maintain psychological safety. A complete description of the competition and the differences between the two simulation modalities can be found in **Table 1**.@@[23, 24]

Questionnaire development

To develop a questionnaire to explore participants' opinions of avatar and distance simulation compared to conventional SBE, we used a three-round modified Delphi technique. The Delphi technique allows easy curriculum revision, as investigators can work at a distance with various target group representatives. It provides opinions from a broad range of experts to be consolidated into a manageable number of precise statements. This technique defines that "pooled intelligence" captures the collective view of stakeholders (25).

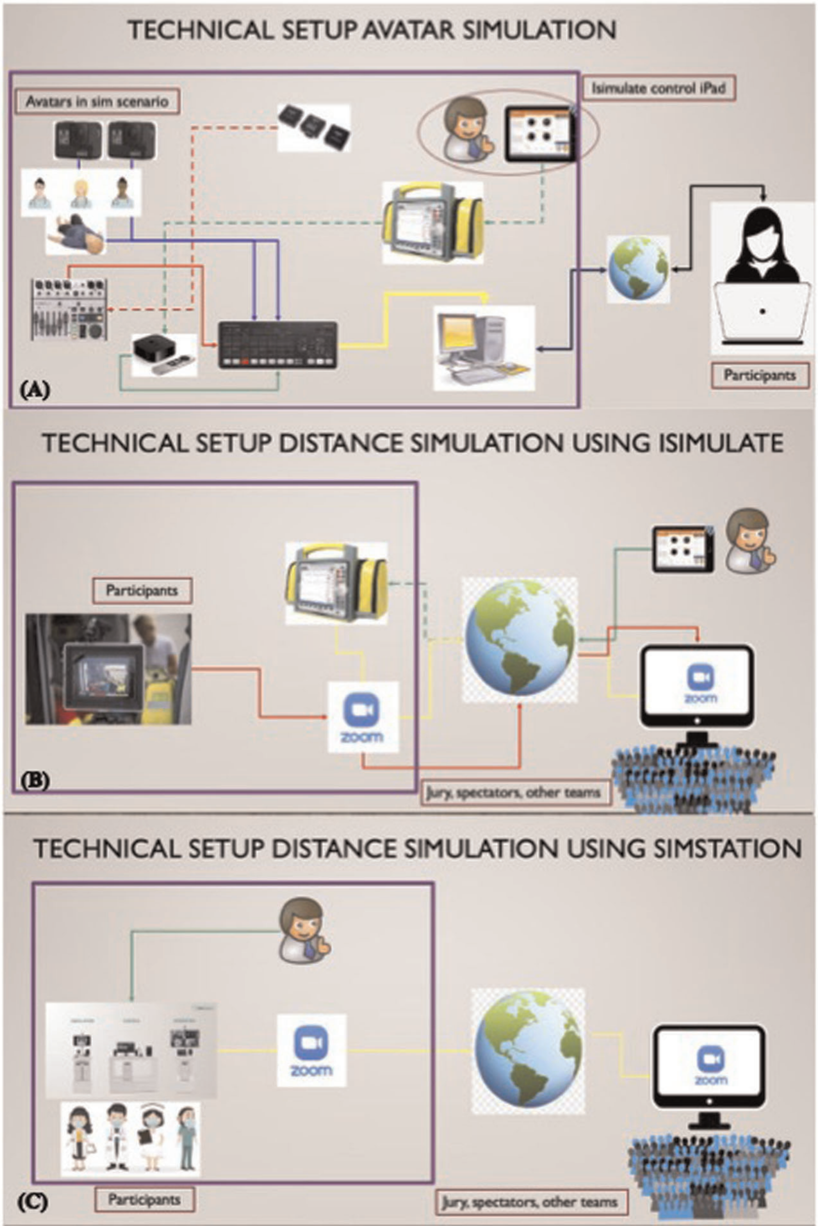

FIGURE 1
Concepts and technical setup of (A) avatar simulation and distance simulation using (B) iSimulate (iSimulate, Canberra, Australia and albany, New York, United States) or (C) SIMStation (©SIMStation, Vienna, Austria), respectively. Figures courtesy of Dr. Alberto Gyasi, Vienna, Austria. (A) On site: Control of the iSimulate monitor *via* the iSimulate control pad, which transmits the image of the monitor *via* radio to the Apple TV (Apple TV®, Apple Inc., United States) device. The Apple TV® device transmits the image to the video mixer [Atem mini (Blackmagic Design Pty. Ltd, Port Melbourne, Australia)] *via* HDMI. The two GoPro (©GoPro Inc., United States) cameras each transmit the action *via* HDMI to the video mixer. The Avatars transmit their sounds *via* wireless microphone to the wireless receiver. The wireless receiver feeds the sound to the video mixer *via* cable. The video mixer provides picture and sound to the participants *via* a virtual webcam over Zoom® (Zoom Video Communications, San Jose, California, United States). Participants side: Participants also use Zoom® to give instructions to the avatars *via* a speaker in the avatar room, allowing them to remotely control the avatars. (B) On-site: One iPad® (Apple Inc., United States) is used as an iSimulate patient monitor, another iPad® as a camera. Both must be connected to Zoom® to transmit the respective image. In the control center: The patient monitor can be controlled *via* an iPad®, which is connected to the monitor *via* internet. In addition, the two images from the remote simulation site are pinned (or brought into focus) on Zoom®. At a distance: That way the spectators and jury can follow the simulation. (C): On site: ©SIMStation (with inbuild cameras capturing the team and the monitor) needs to be connected to Zoom®. The patient monitor is controlled on site. At a distance: That way the spectators and jury can follow the simulation.

FIGURE 2
Participant and facilitator zoom®screen views. (A) Avatar simulation. Side-by-side format showing the operator's (technician's) shared screen of patient monitor vitals from a distance (located in Vienna), the avatars' video of the simulated scenario and the gallery of participants, facilitators [jury members located in Stockholm (RML), Münster, Germany, and Bellinzona, Switzerland] and operator (technician), located in Vienna, Austria. Operator is in the same room and behind the camera. (B) Distance simulation using ©SIMStation. Side-by-side format showing the ©SIMStation's three camera views and local confederate operator's shared screen of patient monitor vitals transmitted *via* connection to Zoom®. (C) Distance simulation using iSimulate. Side-by-side format showing the operator's (technician's) shared screen of patient monitor vitals from a distance (Vienna) and the participants' video of the simulated scenario transmitted by a camera connected to Zoom®.

TABLE 1 Description of the simulation competition.

	Avatar simulation	Distance simulation
Teams	One coach (pediatric specialist), one nurse, three pediatric specialists in training	One coach (pediatric specialist), one nurse, three pediatric specialists in training
Scenario	We ran the same scenario* (supraventricular tachycardia case) four times. Avatars acted solely to orders from the participating teams and were addressed by the colour of their scrubs (which acted as a name)	Two different scenarios* (drowning and status epilepticus) were run twice each for teams 1 + 2 and 3 + 4, respectively.
Technical details	Teams, jurors, and avatars joining a Zoom conference, avatar team and monitor pitched to Zoom screen using iSimulate software (23).	Teams, jurors, and audience joining a Zoom conference, participating team and monitor pitched to Zoom screen using SIMStation software (24) (own monitor, $n = 2$, operated by confederate) or iSimulate software (23) ($n = 2$, operated by organising team/juror).
Audience	None	Conference workshop participants ($n = 12$), observing the competition and participating in the feedback/medical debriefing session.
Organising committee	Jurors: RML (pediatric emergency medicine), located in Sweden, one juror located in Switzerland (pediatric emergency medicine) and 1 in Germany (paediatrics), respectively Technical support: Pediatrics specialist, Austria, physically located in Vienna	Jurors: RML (pediatric emergency medicine), located in Sweden, one juror located in Switzerland (pediatric emergency medicine) and 1 in Germany (paediatrics), respectively Technical support: Pediatrics specialist, Austria, physically located in Vienna
Evaluation	60-point scale scoring sheet**, points and penalty points for various performed or omitted medical and non-medical tasks	60-point scale scoring sheet**, points and penalty points for various performed or omitted medical and non-medical tasks
Debriefing	15-minute presentation-based, interactive summary of medical aspects of each scenario for all participants and audience	15-minute presentation-based, interactive summary of medical aspects of each scenario for all participants and audience; separate teamwork-oriented virtual debriefing session with each team and without an audience the day after the competition

*The original scenarios are available on request by the authors.
**The original scoring sheets are provided as supplementary files 3a-c.

The recourse was taken to five simulation education experts who were not part of the competition jury. RML drafted the first version of the questionnaire, which was composed of open and multiple-choice questions as well as questions using a Likert-like scale with 1 representing "Extremely little/low", 2 "Very little/low", 3 "Low/little", 4 "Neutral/average", 5 "Well/much", and 6 "Very well/much", and 7 "Extremely well/much". All Delphi rounds were developed iteratively by consultation and feedback. In the first Delphi round, we used open-ended questions with the scope of prioritizing and putting across the most relevant survey questions and topics for avatar and distance simulation.

Participating stakeholders were asked to comment on the content, comprehensibility, grammar/spelling, completeness, and relevance of the survey items to suggest changes or decide whether the items should be included in the final competence list. All participating stakeholders were invited by e-mail to answer the questionnaire. An e-mail reminder was sent 14 days after the initial invitation. After completing the first round, the facilitator (RML) read all the answers to the open questions, edited, merged similar answers/suggestions, and grouped them into categories to compile the second-round questionnaire. All stakeholders participating in round 1 were invited by e-mail to the second round to rate each statement. The second round consisted of a repeat review of the edited survey items regarding content, comprehensibility, grammar/spelling, completeness, and relevance in this edited version. Items included in the questionnaire were again re-piloted, and final edits were made based on the feedback. In the third round, the penultimate list was again sent to all the stakeholders to comment on and sign. At the end of Delphi round 3 a consensus was reached, resulting in the final 32-item version of the survey (original questionnaire in German and English translation thereof, **Supplementary Files 1, 2**). The final online version was pilot tested for ease of completion and technical functioning by two German-speaking stakeholders to confirm its comprehensibility and the usefulness of the response options.

Simulation competition participant survey

After the workshop, all four participating teams were surveyed using the previously developed 32-item online questionnaire (**Supplementary Files 1, 2**). The survey link was sent to all potential study participants following the simulation competition, including a covering letter reiterating the study's goals. The questionnaire aimed to explore the participants' experience with avatar simulation and distance simulation. The survey was distributed electronically using the SurveyMonkey® tool (SurveyMonkey Inc, San Mateo, California, United States). As all participants who enrolled in the workshop were eligible for inclusion in the study, we used a non-probability convenience sample.

The advantages of avatar and distance simulation, based on the qualitative analysis of open-ended questions (see Data analysis), and limitations and barriers of both simulation modalities, were declared as our primary outcomes.

The secondary outcomes included satisfaction with avatar and distance simulation, ability to immerse into and psychological safety with the avatar and distance simulation modes, availability of non-verbal information, preference for distance vs. presential simulation modalities, and preference for virtual or hybrid vs. presential simulation in the future.

Participant demographics [age, gender, home country, simulation experience in years, previous virtual simulation experience (distance, avatar, telesimulation, or virtual reality simulation)] were recorded. We also collected the study participants' experiences regarding audiovisual broadcasting technology.

Data analysis

We used SPSS v26 (IBM, New York, United States) to analyze quantitative data. We performed a descriptive analysis of the survey data. Categorical variables were described as absolute (n) and relative frequencies (%). Missing answers are accounted for by listing the total absolute number for each item (different from 20) where not all 20 respondents answered a question. Continuous variables were described using median and 25th–75th quartiles. Individual items were assessed for normal distribution with the Shapiro–Wilks test and visual assessment of residuals and Q–Q Plots. Due to the nature of the data and the small sample, we used the Mann–Whitney *U*, Kruskal–Wallis or Wilcoxon signed-rank tests for continuous variables and the Chi-square test or Fisher's exact test for categorical variables. An *a priori* probability of less than 0.05 was considered statistically significant. For reliability testing of the survey, internal consistency was evaluated with Cronbach's alpha (Cronbach's alpha = 0.7) (JB-E). We considered a Cronbach's alpha of ≥0.7 as reliable (26).

The qualitative analysis of open-ended questions was performed by two authors (JB-E and RML) using an inductive approach and a thematic content analysis (27). JB-E performed answer reduction, and RML cross-checked answers. We used open coding to check for common themes and categories of open-ended questions. Open codes were re-analyzed for duplications and overlapping themes. Final code verification was attained through peer debrief.

Results

Four teams (Germany $n = 1$, Austria $n = 3$, total participants $n = 20$) participated in the study. Participant characteristics are presented in **Table 2**.

TABLE 2 Participant demographics.

	Total ($n = 20$)
Age [years, Median (Q25–Q75)]	34.0 (29.0–41.0)
Female gender (n, %)	11 (55.0)
Country of workplace	
Austria	11 (55.0)
Germany	7 (35.0)
No answer	2 (10.0)
Simulation experience [years, Median (Q25–Q75)]	4.0 (2.5–7.5)
Previous experience in virtual/distance simulation	2 (10%)

Survey results – technical aspects

Most participants attended the sessions using their computer or tablet with a camera and microphone. Only a small percentage (20%, $n = 4/20$) used the mobile phone. Regarding connection issues during the sessions, 40% ($n = 8/20$) of participants reported audio problems, and 25% ($n = 5/20$) reported video problems during the live broadcast. Most frequently reported problems included the inability to read the information on the screen (57.1%, $n = 8/14$), the commands to the avatars not being heard or misinterpreted (28.6%, $n = 4/14$) and frozen video transmission (14.2%, $n = 2/14$). These issues led to simulation delays on four occasions (20%). There were no differences between males and females in reporting audio ($p = 0.619$) or video ($p = 0.371$) issues. Participants managed to immerse themselves well in the avatar simulation [5.0 (3.0–5.0)] but received little non-verbal information from the avatars [5.0 (3.0–5.0)].

Survey results – comparison of distance, avatar and face to face simulation

Participants' satisfaction with distance simulation was higher than with avatar simulation, but this difference was not statistically significant ($z = -1.00$, $p = 0.317$). We found no difference in the generally high rating of psychological safety in both simulation types (**Table 3**). However, compared to presential simulation, only 20% of participants ($n = 4/20$) believed that avatar simulation offered more psychological safety, while distance simulation was considered psychologically safe in 30% ($n = 6/20$) of cases. There were no

TABLE 3 Satisfaction and psychological safety with avatar simulation and distance simulation.

	Avatar Simulation	Distance Simulation	p-value*
Satisfaction [Median (Q25–Q75)]	5.0 (4.0–6.0)	6.0 (5.0–6.0)	0.317
Psychological Safety [Median (Q25–Q75)]	5.0 (4.0–6.0)	5.0 (5.0–6.0)	0.480

*Wilcoxon signed-rank test. Satisfaction and psychological safety were rated on a Likert-scale from 1 (Extremely little) to 7 (Extremely much) for satisfaction, and 1 (Extremely low) to 7 (Extremely high) for psychological safety, respectively.

TABLE 4 Reported advantages and challenges with avatar and distance simulation.

	Avatar simulation	Distance simulation
Advantages	• No travel distances ($n = 10/30$, 33.3%) • Lower costs ($n = 9/30$, 30.0%) • Less time required ($n = 9/30$, 30.0%) • Less exposure to other participants or educators ($n = 1/30$, 3.3%) • Other ($n = 1/30$, 3.3%)	• No travel distances ($n = 14/44$, 31.8%) • Lower costs ($n = 10/44$, 22.7%) • Less time required ($n = 7/44$, 15.9%) • Less exposure to other participants or educators ($n = 2/44$, 4.5%) • Simulation in real working environment ($n = 10/44$, 22.7%) • Other ($n = 1/44$, 2.2%)
Challenges	• Technical problems ($n = 9/38$, 23.7%) • Streaming delays ($n = 5/38$, 13.2%) • Fewer non-verbal cues ($n = 9/38$, 23.7%) • Spatial distance from team ($n = 9/38$, 23.7%) • Feeling “hands tied” ($n = 4/38$, 10.5%) • Other ($n = 2/38$, 5.2%)	• Technical problems ($n = 16/37$, 43.2%) • Technology time delays ($n = 8/37$, 21.6%) • Spatial distance from team ($n = 12/37$, 32.4%) • Other ($n = 1/37$, 2.7%)

significant differences between men and women for satisfaction with the simulation (avatar: $p = 0.388$; distance: $p = 0.313$), for psychological safety (avatar: $p = 0.755$; distance: $p = 0.0713$) and for the ability for immersion ($p = 0.662$) and reception of non-verbal cues ($p = 0.628$) in the avatar simulation. Overall, the Likert-scale items in the survey showed an internal consistency of $\alpha = 0.763$. Reported advantages and challenges for each type of simulation compared with traditional presential simulation are listed in Table 4. Regarding preferences for different future simulation types, responders did not show any interest in changing to avatar simulation only ($n = 8/20$, 40%). They also seemed to prefer presential simulation to distance simulation ($n = 7/20$, 35%) but showed interest in having presential and avatar/distance options or hybrid options available.

When asked about psychological safety, respondents mentioned that during presential simulation there was easier communication and engagement in teamwork, more direct contact with other participants, less hesitancy to talk about emotions, easier understanding of non-verbal cues, and more authentic debriefing. As for avatar simulation, limited involvement of trainers, a reduced feeling of being examined, less shame when giving wrong answers, and the physical distance between trainers and participants were considered beneficial for psychological safety. Statements were similar for distance simulation, including being less on display, suffering less from exam stress, valuing the training in a familiar working environment and trainers feeling more like supervisors.

Responses related to general learning experiences with virtual simulation are summarized in Table 5.

Discussion

Participants indicated a high overall satisfaction with avatar and an even higher, although statistically non-significant, appreciation of distance simulation in this Central European survey study. Our hypothesis that there would be distinct but

TABLE 5 Reported reasons why different types of simulation offer psychological safety in different ways and reported learning experiences from distance simulation.

Reported reasons why presential simulation enhances psychological safety:
Easier communication and engagement in teamwork
Easier to receive direct and complete feedback
More direct and immediate contact with the other participants
Getting to know the other participants personally
Less inhibition to talk about emotions
Easier understanding of non-verbal cues
More effective and authentic debriefing with participants and debriefer physically in the same room, (*full*) debriefing directly after the scenario
Atmosphere is more authentic/ direct and less anonymous
“No unknown number of (invisible) spectators” (n=2) (*This was the case in this simulation competition*)
“This may only be a subjective psychological safety”
Reported reasons why avatar simulation enhances psychological safety:
Trainers may have a better overview from a distance, may be less involved in the simulation
Less feeling of shame when giving wrong answers
The physical distance between trainers and participants conveys a feeling of security
Less exam feeling
Reported reasons why distance simulation enhances psychological safety:
Simulation in familiar working environment
“Trainer feels more like a supervisor”
Less feeling of being on display
Less exam stress
Reported specific learning experiences with distance and avatar simulation:
Preparation and possibility of technical equipment/technology
Possibility of interaction with different involved persons who do not need to be physically in the same room
More positive experience than expected, unexpectedly effective team training
More challenging assessment of non-medical aspects in distance, as compared to F2F simulation
New (*virtual*) situation, flexibility
Stresses the relevance of good communication, repeat assessments and keeping calm
"First sim for me in a while so grateful for the experience"
Good opportunity to train team-leadership (*with a focus on clear instructions and structured patient assessment*)
Excellent opportunity for students (*in current and future contexts*)
“Interesting experience, for me more like watching a video or personal algorithm, less like team training”
It is difficult to lead the avatars step for step, but it is good for communication training

*In parentheses, explanatory notes by the authors.

specific advantages of avatar and distance simulation compared to standard SBE was corroborated.

Strengths of avatar and distance simulation

The surveyed participants mentioned several decisive strengths of virtual simulation education in the inaugural virtual simulation competition facilitated by Netzwerk Kindersimulation, e.V. (14). The elimination of travel distances and associated lower costs and less time spent attending the education activity were the most frequently reported items. Although mentioned least commonly, reduced self-exposure to other participants or educators seemed advantageous. Previous participant satisfaction survey-based studies described telesimulation as a good substitute for presential SBE and the fact that they felt more engaged and encouraged to think critically (28). Virtual simulation offers further profits. For example, permitting remote specialists or colleagues to participate as educators or debriefers on a topic they are experts in and thereby offers widened expertise to the participants on the one hand, and peer coaching or debriefing of the debriefing among experts on the other hand (29). It has been recommended that simulation educators regularly get feedback on their debriefing performance, which could be facilitated more easily through virtually attending and more experienced debriefing colleagues (21). This concept, called telementoring, has resulted in high-quality debriefings involving remote and local instructors to facilitate effective debriefing during telesimulation (29).

It has been described that simulation integrated into the actual working environment (*in situ simulation*) entails the chance to improve reliability and safety in high-risk areas. In addition, it allows the identification of latent clinical and system threats to patient safety. It provides realism through deliberate practice and integration of interdisciplinary and interprofessional teamwork skills in the time-pressured clinical context. Ultimately, it leads to change in clinical care systems and improved clinical outcomes (30).

Another reported unique benefit of avatar simulation included a positive learning experience due to the more pronounced and newly learned relevance of direct, clear, and structured communication and team leadership when leading the avatars. To our knowledge, this effect has not been previously reported. Whilst the evidence base for this effect is still in its infancy, the same effect has been described with blindfold team training and closed-loop communication. Like leading a team of avatars at a distance, blindfold training is hands-off. It requires critical thinking skills, a conceptual framework, and highly specific and transparent communication within the team to prevent communication errors (31).

Regarding distance simulation in particular, attendance of the simulation event in the own familiar working environment was a commonly mentioned win. Interestingly, one participant stated that the passive attendance of a scenario managed by a competitor team felt like "watching a video or personal algorithm training, less like team training". While this (individual) impression could be seen as a potential limitation of avatar simulation for team training (due to limited immersion into the avatar environment and suspension of disbelief), it may simply reflect the need to develop this simulation modality further and implement it purposefully.

Avatar simulation

An avatar is a concept that originated within Hinduism that signifies a deity's material appearance or incarnation. In computing, an avatar is a graphical representation of a user in a virtual environment (32). It may take either a two-dimensional form as an icon (also known as a profile picture) or a three-dimensional form, e.g., in games or virtual worlds (33). Avatars originated in the world of gaming as popular components of virtual reality (VR). VR formats are increasingly used in healthcare for education and patient distraction preoperatively or during painful procedures (34).

While avatar research is still in its early stages, evidence suggests that those who receive tailored guidance and advice from these virtual agents appear to have better physical and psychosocial outcomes. One explanation is that the digital characters can be customized for cultural, social, and other user preferences (35). Avatars are also being progressively used in medical simulations (36). Immersive, three-dimensional worlds have been created in VR, which may even incorporate multisensory feedback to ensure students pick up essential skills and applications in different healthcare contexts (37, 38). Simulation participants in our study mainly were "novices" regarding the distance simulation construct, whilst it is assumed that they are competent in managing pediatric emergencies. Thus, a lack of concept familiarity may partly explain that most participants would have preferred presential simulation. Motivation to engage in virtual simulation also likely varies from actual patient care. Learners may choose a faster path to the perceived correct answer or be willing to perform educated guessing with less information in a low-stakes, no-patient-harmed environment (39), e.g., telesimulation. Previously reported profits of telesimulation are improved interinstitutional networking and collaboration and rapid dissemination of new medical contents (5).

Face to face simulation

Presential simulation was the gold standard before the COVID-19 pandemic, and we expect this simulation mode to remain a mainstay of modern healthcare education and training. The apparent advantages with presential simulation indicated by the participants included more accessible communication and engagement in teamwork, mainly through non-verbal cues and capture of emotions, more direct contact with other participants and educators, and more authentic debriefing. Moreover, presential simulation requires less costly and time-consuming technical preparation efforts by the facilitators. Some avenues worth exploring in the future comprise the extent to which virtual simulation is comparable to traditional presential simulation, more targeted exploration of potential benefits, e.g., economic savings, time conservation and standardization of scenarios. Although our study did not evaluate whether distance simulation is equivalent to traditional presential simulation in assessing candidates' practical/learning skills, one can envision applying advanced virtual simulation technology to alleviate some of the barriers encountered in the current process. Accordingly, Abulfaraj et al. found no difference in learning outcomes after VR and high-fidelity manikin-based simulation training (40).

In addition to reducing travel distances and costs, virtual simulations can be administered from any remote location with computer access and at any time of day. Thus, simulations could be completed while on remote rotations or at a remote testing site, travelling or at home, across different time zones and countries. Many aspects of virtual simulation require exploration before such technology can be appropriately implemented for general use. Faculty perceptions and experiences need to be evaluated. Additionally, this format must be assessed for limitations regarding reliability, interobserver agreement, and available outcomes in formative and evaluative settings. In our study, participant feedback regarding further willingness to participate in distance simulation was overwhelmingly positive. In this study, many participants would have desired more interaction with the avatar, especially non-verbally and within the scenario. With currently available animation and programming capabilities, we can improve future simulations. Transition to automated scenarios without a real-life proctor could be achieved by applying artificial intelligence (41).

Psychological safety - benefits

Likewise, participants perceived psychological safety as equally high with both virtual simulation types. Psychological safety is crucial for the successful use of SBE. It can be described as people's perception of the consequences of taking interpersonal risks (e.g., speaking up, asking questions, disclosing thoughts and mental frames) in contexts such as a workplace or an educational setting (42, 43).

Interestingly, participants felt that simulation at a distance from the trainers added a feeling of security and less exam stress, feeling of being on display or shame than presential simulation. These comments certainly underline the paramount importance of carefully setting the ground for psychological safety before each training, whether presential or virtual (43).

Challenges with avatar and distance simulation

In contrast, propounded challenges by the participants included technical problems (23.7% with avatar and 43.2% with distance simulation) and the fact that the nature of virtual simulation incurred fewer non-verbal cues (23.7%) for avatar simulation and a spatial distance from the team (23.7% for avatar and 32.4% for distance simulation). Likewise, a previous learner satisfaction survey based study found poor ratings for audio quality (5.22, 6.63 and 5.8 on a 10-point Likert scale for the statement "I could hear the facilitator and other participants clearly") during telemedical resident education (28), and technical issues related to network connectivity or sound quality during telesimulation for medical students neonatal resuscitation training in 75% (8). In our setting, facilitation of the virtual simulation competition relied entirely on the technical support of one institution without a backup institution. The encountered technical impediments can likely be eliminated with upgraded hardware and system capabilities. Furthermore, avatar simulation participants felt their "hands were tied" (10.5%). Contrarily, the occurrence of connection issues was relatively low, but some participants reported streaming and communication problems.

Psychological safety – obstacles

The presence of spectators ($n = 12$), a delayed full debriefing, lack of direct contact with team members (avatar simulation) and a specific inhibition to discuss emotions during virtual simulation were reported as disadvantageous. Again, these comments highlight the importance of ensuring a high degree of psychological safety before the education activity by, e.g., underlining confidentiality and attributing enough time for debriefing (43).

Only 10% of the competition participants had previously participated in a virtual simulation. Nevertheless, participants managed to immerse themselves well in the avatar simulation, a new simulation environment for most participants, even though they reported restricted reception of non-verbal information from the avatars.

Despite the discussed profits and satisfaction with virtual simulation, none of the respondents wanted to convert to avatar simulation only ($n = 8/20$, 40%) or seemed to prefer presential simulation to distance simulation ($n = 7/20$, 35%). However, they showed an interest in having future hybrid presential and avatar/distance options available.

General learning experience

Interestingly, most participants stated that especially avatar simulation offered a new and unexpectedly effective opportunity to specifically train effective communication, structured patient assessment and leadership skills. Both avatar and distance simulation formats generally provided the opportunity to participate in any simulation training at all, certainly underlining the beneficial win of equity for both remotely located medical and nursing students and health care providers and trainers (29).

Limitations of the study

We acknowledge a small sample size in our study, where we investigated the preferences and opinions of a relatively small group of selected subjects in a very particular environment. Additionally, a subset of answers was missing due to a few incompletely answered questionnaires. Also, the avatar simulation was facilitated at a single academic training site. This research is based on participants' opinions, judgements, statements, and viewpoints that are not conclusive or scientific evidence compared to research data. All these factors may limit the generalizability of our results.

Furthermore, we investigated the feasibility of administering a virtual simulation in a competition setting; however, we did not evaluate the effectiveness of virtual simulation in assessing participants relative to a standard presential simulation. We did not specifically investigate the ability to immerse into distance simulation as we considered the *in situ* setting familiar to the participants but with the assessor/trainer at a distance. The simulation scoring tool used in this study was modified from the evaluation tools used in conventional simulation. From an educator's point of view, current evaluation tools might not be relevant to the new virtual environment. Thus, evaluation tools for virtual might need to be updated, or faculty may need to develop new tools specifically designed for the characteristics of distance simulation. We collected previous simulation experience but not experience in years in the clinical setting. We can, therefore, only assume that the trainees (4×3 junior trainees) had less experience than the specialists (4×1 senior physician), possibly causing cognitive bias.

Conclusion

The results from this small but innovative pilot study will inform simulation educators about target group reported advantages and challenges of avatar and distance simulation modalities both in competition and training settings. While we fully acknowledge and emphasize the value of presential SBE, our findings suggest avatar-based simulation formats as a promising learning tool for targeted communication and leadership skills training for medical students and interdisciplinary and interprofessional teams in current and future education beyond the pandemic.

Although these findings may not be conclusive, they may undoubtedly inform future studies exploring the challenges and opportunities of different virtual simulation modalities and studies examining the experience and the degree of psychological safety in the virtual simulation context more extensively.

To date, presential training remains the gold standard of simulation-based education. However, virtual simulation training modalities will remain relevant for maintaining SBE during COVID-19 and other pandemics, forcing educators and learners to adhere to social distancing requirements while aiming to continue essential training activities.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The Institutional Review Board at Karolinska University Hospital, Stockholm, Sweden (File number 2021 02983, June 29, 2021) waived the need for ethics approval as per local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

Author contributions

LPM: Interpretation of the data, drafting the first version of the manuscript, revising the work critically for important intellectual content, final approval of the version to be published, agreement to be accountable for all aspects of the work ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. JEB: Analyzing the data, interpretation of the data, drafting the first version of the manuscript, revising the work critically for important intellectual content, final approval of the version to be published. LAR: Data collection, revising the work critically for important intellectual content, final approval of the version to be published. RML: Conception of the work, interpretation of the data, drafting the first version of the manuscript, revising the work critically for important intellectual content, final approval of the version to be published, agreement to be accountable for all aspects of the work ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The reviewer [PS] declared a shared affiliation with one of the authors [LR] to the handling editor. RML and LPM receive per diem honoraria from Paedsim e.V. team training for paediatric emergencies. RML received funding from the companies Hipp, Chiesi Pharmaceuticals and 3BScientific for their financial support of the sim challenge educational activity.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fped.2022.853243/full#supplementary-material.

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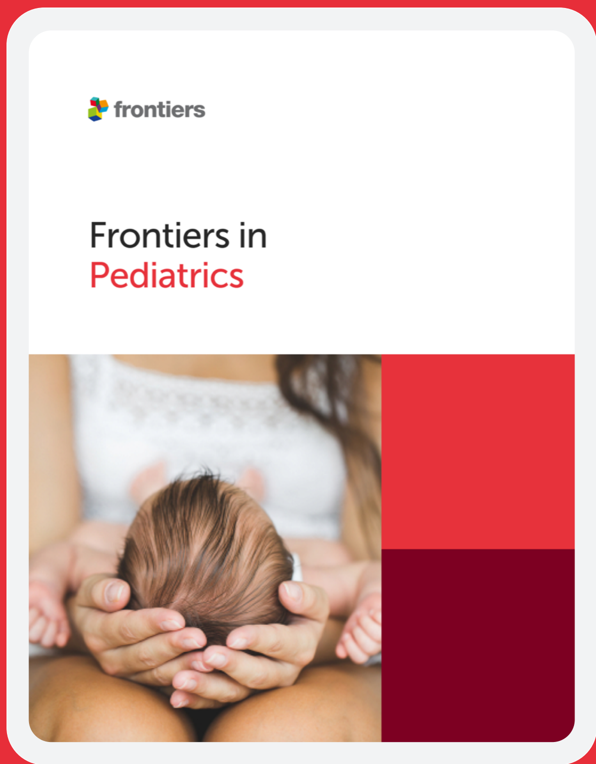

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