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SIMULATION-BASED TRAINING FOR NEONATAL ENDOTRACHEAL INTUBATION: A NARRATIVE REVIEW

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Abstract: Objective: To analyze the impact of simulation-based training on the efficacy of neonatal endotracheal intubation, with an emphasis on simulation methodologies such as high-fidelity mannequins, 3D printing, virtual and augmented reality, and to discuss the comparison between different intubation devices. **Methodology:** A literature review based on articles indexed in the PubMed database. The descriptors used in the search included "endotracheal intubation" OR "airway management" AND simulation OR "mannequin-based training" OR "simulation-based training" OR "high-fidelity simulation". Twenty articles were selected for detailed analysis, considering their relevance to the topic. **Discussion:** Simulation-based training has been shown to be highly effective in improving neonatal intubation performance, particularly in terms of reducing execution time and increasing the success rate on the first attempt. Methodologies such as high-fidelity simulators, 3D printing, and virtual and augmented reality approaches have shown positive results in terms of technical precision and minimizing complications. However, the scarcity of resources and the need for large-scale clinical validation still represent challenges for the universal implementation of these technologies. **Final considerations:** Simulation-based training is an essential tool in the training of health professionals, helping to improve technical skills and safety in neonatal airway management. We recommend expanding the use of these methodologies, as well as developing standardized guidelines for training and encouraging longitudinal studies to optimize clinical results and improve the quality of neonatal care.

Keywords: Neonatal; Endotracheal intubation; Airway management; Simulation; Training with mannequins; High-fidelity simulation.

INTRODUCTION

Endotracheal intubation in neonates is a highly complex medical intervention, essential for the stabilization and recovery of newborns with respiratory failure. This procedure requires refined technical skills and rigorous training, since failures during its execution can lead to severe consequences, such as prolonged hypoxia, respiratory complications and even respiratory collapse (CAVALLIN et al., 2021). Given the importance and delicacy involved, it is imperative to investigate effective training strategies for professionals working in neonatal care.

In recent decades, simulation centers have been widely used as an educational resource to train healthcare professionals in critical procedures, such as neonatal intubation (BAYOUMI et al., 2022). Clinical simulation allows technical skills to be developed in a safe environment, contributing to more assertive decisions under pressure and reducing risks to patient health (ZANNO et al., 2022; GLOMB et al., 2020). However, although its adoption is expanding, there are still questions about its effectiveness compared to direct clinical practice (SCHOPPEL et al., 2023; XIAO et al., 2020).

Despite the advances in the use of simulation as a teaching method, there are still significant gaps in the literature. The lack of standardization in training methods and limited resources in certain institutions make it difficult to uniformly evaluate its results (ZANNO et al., 2022). In addition, there is a lack of robust data that unequivocally demonstrates the impact of simulation on the practical competence of professionals. This justifies a more in-depth analysis of the effectiveness of simulation in teaching neonatal endotracheal intubation.

Recent studies suggest that simulation-based training can significantly improve the effectiveness of the intubation procedure, reduce execution time and increase technical precision (BAYOUMI et al., 2022; XIAO et al., 2020). Continuous exposure to simulated scenarios contributes to the consolidation of skills and prepares professionals to act more safely in real situations (ZANNO et al., 2022).

This review aims to assess the impact of simulation-based training on the efficiency of neonatal endotracheal intubation in hospital settings. It seeks to analyze the extent to which this type of training influences the performance of professionals, identify its limitations and propose strategies to improve its implementation, with a view to promoting safer, high-quality neonatal care.

METHODOLOGY

A literature review developed according to the criteria of the PVO strategy, which stands for: population or research problem, variables and outcome. This strategy was used to develop the research question What is the impact of neonatal endotracheal intubation training in simulation centers on the development and improvement of the technique? The searches were carried out using the PubMed - MEDLINE (Medical Literature Analysis and Retrieval System Online) databases. The search terms were used in combination with the Boolean terms "**AND" and "OR"** using the following search strategy: (neonatal OR newborn OR preterm OR infant) AND ("endotracheal intubation" OR "airway management") AND (simulation OR "mannequin-based training" OR "simulation-based training" OR "high-fidelity simulation"). From this search, **136** articles were found, which were then submitted to the selection criteria. The inclusion criteria were: articles in English published between 2020 and 2025 and which addressed the themes proposed for this research, narrative review-type studies, systematic review, meta-analysis, observational studies, experimental studies. The exclusion criteria were: duplica-

te articles, articles available in abstract form, articles that did not directly address the proposal studied and articles that did not meet the other inclusion criteria. After applying the search strategy to the database, a total of **59** articles were found. After applying the inclusion and exclusion criteria , **20** articles were selected from the PubMed database to make up this study's collection.

DISCUSSION

Neonatal orotracheal intubation (OTI) is a critical procedure that requires precision, speed and a high level of technical skill. However, low practical exposure and lack of experience during the training of health professionals can compromise the effectiveness of the procedure and increase the risk of complications. In this context, different training strategies have been investigated to improve training, including simulations with mannequins, virtual and augmented reality technologies, as well as comparing conventional and video laryngoscopy-assisted techniques.

This section discusses the main approaches used in neonatal OI training, highlighting the impact of simulation-based methodologies on improving clinical performance. Recent studies on the effectiveness of high-fidelity simulation and 3D printed models are analyzed, as well as the advances provided by the use of virtual reality and artificial intelligence in learning the technique. In addition, the comparison between different intubation devices, such as direct laryngoscopy and videolaryngoscopy, is explored, emphasizing the advantages and limitations of each method.

SIMULATION-BASED TRAINING IN NEONATAL INTUBATION

Performing orotracheal intubation (OTI) requires precision and experience, as well as motor coordination and quick decision--making to minimize complications. Recent studies highlight the importance of simulation training to improve the competence of professionals and increase the success rate on the first attempt. These centers allow for the development of the practical skills needed to perform the procedure, provide a controlled and safe environment for improving professionals' skills, and minimize risks to patients.

Orotracheal intubation is an essential procedure in neonatal emergency situations, such as apnea or inadequate respiratory effort, and is indicated when there is a need to ensure a safe and effective airway. Sugiura et al. (2024) demonstrated that simulation-based training significantly improves performance in the insertion of airway devices in neonates, regardless of the length of previous clinical experience. The study indicated that the success rate in insertion within the optimal time was higher for professionals trained with supraglottic devices in neonatal simulators, suggesting that practice in controlled environments can reduce failures and optimize ventilation in real situations. In this context, the practice of OTI is of great importance for medical practice in the management of neonatal complications and resuscitations.

It is necessary to acquire experience and competence in order to perform a medical procedure safely and effectively. That said, Flynn et al. (2024) carried out a study evaluating the success rate of participants after training in the OTI technique prior to neonatal intubation, and observed an increase in the success rate on the first attempt from 81.6% to 91.4%, reducing the mental effort made to perform a certain procedure and improving the assessment of competence. The authors

point out that prior practice on simulators, carried out before the actual procedure, was decisive for these positive results, reinforcing the importance of simulation-based training programs for neonatal safety.

Another relevant study by Rufach et al. (2021) evaluated the use of low-cost videolaryngoscopes in simulated training, showing that repeated practice significantly reduced intubation time between the first and second attempts. All participants were able to successfully perform OTI, indicating that simulation contributes to the development of the technical skills required for the procedure, even among professionals with no previous experience with the equipment. This proves that gaining experience in simulation centers is extremely important for improving techniques and efficiency in execution.

These results highlight the need to include simulation programs in the training of healthcare professionals. Training can not only increase the success rate and reduce the time needed for intubation, but can also reduce the occurrence of complications related to the procedure. Therefore, the adoption of educational strategies based on simulation should be considered indispensable for training in neonatal resuscitation and advanced airway management.

MANNEQUIN SIMULATION: HIGH FIDELITY AND LOW COST ALTERNATIVES

Simulators of different categories are increasingly being used to train endotracheal intubation skills and are proving to be an advantageous way of keeping health professionals in touch with cases that are more difficult to find in health units outside regions with high neonatal demand. As evidenced by the Zanno et al. study (2022), more than two-thirds of hospitals carry out less than one neonatal delivery per day in rural Maine in the United States, which makes it increasingly difficult to maintain practical techniques and confidence in performing the intubation procedure on neonatal patients. The American Heart Association has encouraged frequent simulation as a continuing education methodology, thus improving various aspects of medical conduct such as: improving care, improving communication between the emergency care team and the acquisition and retention of knowledge.

Education programs applied in realistic simulation centers that contain high-fidelity neonatal simulators are measures that, when adopted, improve student skills and help protect neonates from possible harm, improving neonatal outcomes in general. The outdated methodology previously applied in medical education to teach procedures only on cadavers or in an exclusively theoretical way (in the absence of real cases for training) made it impossible for students to experience clinical practice, resulting in many pediatric residents finishing their training without endotracheal intubation skills (BAYOUMI et al., 2022).

The training carried out during the first year of the Neonatal Simulation Program in Qatar, as shown in the study by BAYOUMI et al., 2022, contributed positive results to improving professional training in neonatology. Before the participants were trained, the average time taken to perform an endotracheal intubation was between 12.5 and 9.2 seconds, with a first attempt success rate of 26.6%. At the end of the training, these professionals underwent a reassessment, where the average time became 4.2 to 3.8 seconds, with a success rate of 75.5% in real patients.

According to Lejus-Bourdeau et al. (2023), clinical simulation for the management of complicated airways, such as intubation in cases of glottic edema, continues to be one of the main causes of morbidity due to neonatal physiology, which contributes to rapid hypoxemia during apnea. Training in the management of

these conditions should therefore be carried out using simulators that are not only high-fidelity, but also low-cost. The main factors that contribute to learning during a simulation are the environment in which the professionals find themselves, where various aspects lead to immersion in the case, and not necessarily the technical characteristics of the simulator. These include briefing and debriefing by the same instructor, the importance of monitoring vital signs and an interactive approach to the clinical situation presented. simulations can offer valuable knowledge beyond technical skills, such as managing a team in crisis situations.

One perspective presented as a solution for institutions that cannot afford a high-fidelity simulator would be 3D printing of anatomical structures. According to the research methodology used, no results were obtained for intubation, but for cricothyroidostomy, which proved to be an efficient alternative due to the possibility of printing the structure of the upper airway of neonates in various sizes, which are currently difficult to access with regard to the sale of simulators (HAMPTON; DAVIS; KALNOW, 2020).

VIRTUAL AND AUGMENTED REALITY IN NEONATAL INTUBATION SIMULATION

Neonatal endotracheal intubation (ETI) is an essential procedure to ensure adequate ventilation of newborns in emergency situations. The anatomy of neonates presents greater challenges for healthcare professionals, including narrow airways, making ETI a complex skill that requires rigorous training (XIAO et al., 2020). However, the low success rate among pediatric residents ultimately highlights the limitations in traditional methods of teaching the technique, suggesting the need for more effective approaches (ZHAO et al., 2020).

Conventional ETI training is based on physical mannequins, on which students practice under the supervision of experienced instructors. Although this approach offers learning opportunities, it has limitations such as the low anatomical variation of the mannequins, difficulties in objectively assessing performance and the need for instructors to be available to accompany each student in their practice session (MENG; HAHN, 2023). These restrictions end up having a negative impact on the quality of training and the acquisition of the skills needed to safely perform the technique in real clinical scenarios.

With the advance of simulation technologies, new approaches to this training have emerged, incorporating virtual reality (VR), augmented reality (AR) and machine learning. These innovations aim to overcome the barriers of conventional methods, providing more immersive training experiences and bringing accurate and automated assessments of trainee performance (XIAO et al., 2020).

Virtual reality-based simulators have revolutionized TSI training by allowing students to practice in a highly interactive virtual environment. These systems use detailed anatomical models generated from CT scans, ensuring a faithful representation of neonatal structures (XIAO et al., 2020). In addition, VR technology allows scenarios to be customized, enabling learners to face different clinical challenges and vary the levels of difficulty during practice (ZHAO et al., 2020).

To make the simulation more realistic, VR systems employ the technique of position-based dynamics, allowing accurate modeling of soft tissues, bones and fluids. This approach allows medical instruments such as laryngoscopes and endotracheal tubes to be manipulated realistically, taking into account tissue resistance and anatomical reactions (XIAO et al., 2020). Another differential is the incorporation of haptic feedback, which offers tactile

sensations to the user, improving perception and control of movements during intubation (XIAO et al., 2020).

Augmented reality (AR) has also been applied to TSI training, offering an innovative approach that combines virtual elements with the real environment. Unlike VR, which creates a completely digital environment, AR projects visual information onto physical mannequins, allowing learners and instructors to have an expanded view of neonatal anatomy in real time (ZHAO et al., 2021).

AR systems use electromagnetic sensors and motion tracking to capture students' gestures and map the position of the laryngoscope and endotracheal tube. In this way, instructors can visualize the insertion of the tube into the manikin's airway, making it easier to identify errors and allowing for immediate corrective interventions (ZHAO et al., 2021).

One of the main benefits of RA is the possibility of providing a "transparent" view of the mannequin, eliminating the difficulties associated with internal visualization of the procedure. This functionality improves understanding of the correct technique and reduces the need for direct instructor supervision, making training more efficient and accessible (ZHAO et al., 2021).

Performance evaluation in ETI traditionally relies on direct observation by experienced instructors, which can result in subjectivity and inconsistencies. To mitigate these limitations, researchers have developed automated systems based on machine learning, capable of analyzing performance parameters and providing standardized and objective evaluations (MENG; HAHN, 2023).

Deep learning models, such as convolutional neural networks (CNN), have been applied to identify patterns in learner movements and classify performance based on pre-established criteria. Some studies indicate that these systems have achieved up to 93.6% accuracy in classifying intubation attempts, demonstrating great potential for standardizing assessment (MENG; HAHN, 2023).

Despite the progress offered by emerging technologies, some limitations still need to be addressed to optimize their effectiveness in endotracheal intubation (ETI) training. One of the main challenges is improving haptic feedback, which must be adjusted to more accurately simulate the resistance of neonatal tissues during the procedure (XIAO et al., 2020). In addition, the modeling of fluids, such as saliva and secretions, still needs refinements to make the experience more realistic (XIAO et al., 2020).

Another important aspect is the need for large-scale clinical validation. Although initial studies have shown significant benefits, longitudinal research is needed to assess the impact of these technologies on the training of health professionals and patient safety (MENG; HAHN, 2023).

VIDEOLARYNGOSCOPY AND SUPRAGLOTTIC DEVICES IN NEONATAL AIRWAY MANAGEMENT

Training using simulators aims to improve healthcare professionals' knowledge of planned procedures, providing greater contact with clinical scenarios and increasing the success rate in Orotracheal Intubation. It is therefore important to analyze the different pieces of equipment used. One of the main interventions in neonatal resuscitation involves the use of ventilation devices, such as the orotracheal tube, laryngeal mask and i-gel mask. In this scenario, studies have emerged comparing the effectiveness and insertion time of the latter two devices, seeking to assess which performs best in different clinical contexts.

Sugiura et al. (2024) analyzed the use of laryngeal masks and i-gel in anesthetized children and observed similar success rates for both devices. However, the studies reviewed presented divergent results in terms of insertion time.

While some studies indicated that i-gel allows for faster insertion, a randomized study of 54 babies under 10 kg found no significant differences between the devices. Another study, with 60 pediatric patients between 10 and 25 kg, found that the Supreme laryngeal mask had a shorter insertion time than the i-gel. These findings suggest that the effectiveness of airway management varies according to the type of patient, the clinical condition (resuscitation or anesthesia) and the experience of the professional. Furthermore, considering that the studies were carried out in different settings, more clinical research is needed to validate these comparisons in neonates.

In addition to supraglottic devices, another technology that has been studied in neonatal airway management is the videolaryngoscope. Its use in neonatal resuscitation has shown potential to increase the first attempt success rate and reduce complications, especially in patients with difficult airways. This is because the videolaryngoscope provides better visualization of the glottis, making it easier to insert the endotracheal tube. However, despite these benefits, its use is still limited in many hospitals, mainly due to its high cost. A study by Rufach, Santos and Terebiznik (2021) indicated that although only 10.5% of intubation procedures use this technology, its use has increased in pediatric intensive care units. In view of this, medical societies recommend associating the videolaryngoscope with simulator training, as this practice improves the execution of the technique and helps to anticipate clinical challenges.

Training with simulators has proved to be an essential tool for training professionals in neonatal airway management, allowing contact with different clinical scenarios and increasing the success rate in orotracheal intubation. In the study by Rufach et al. (2021), 18 doctors took part in simulated training, 15 of whom had their times analyzed. The average intubation time fell from 116.4 seconds on the first attempt to 44.2 seconds on the second, demonstrating that repetition of the practice significantly improves the efficiency of the procedure. These findings reinforce the importance of simulation for technical improvement and neonatal safety, highlighting the need for its regular incorporation into the training of professionals in the field.

FINAL CONSIDERATIONS

The purpose of this literature review was to investigate the impact of simulation-based training on the effectiveness of neonatal endotracheal intubation, considering the technical challenges of the procedure, the limitations of traditional teaching and the technological innovations that have been incorporated into the training of health professionals.

The analysis showed that clinical simulation has become an effective teaching tool for developing practical skills, especially in highly complex procedures such as neonatal intubation. The studies reviewed show that training with simulators - whether they are high fidelity, 3D printed, based on virtual or augmented reality - contributes to improving technical performance, increases the success rate on the first attempt, reduces the time it takes to perform the procedure and minimizes the risk of complications. In addition, emerging technologies such as machine learning have expanded the possibilities for objective performance evaluation, providing precise and standardized feedback to apprentices.

However, despite the progress made, significant challenges remain. The lack of standardization in training programs, limited resources in smaller institutions and the need for large-scale clinical validation still restrict the universal adoption of these technologies. In addition, the realism of haptic feedback and the modeling of more complex physiological conditions remain critical points for improvement.

Given these findings, it is possible to state that simulation-based training should not be seen as complementary, but rather as essential in the training of professionals working in neonatology. We therefore recommend continued investment in simulation infrastructure, the development of standardized training guidelines and the promotion of longitudinal studies investigating the impact of these approaches on clinical practice and neonatal outcomes.

Finally, it can be concluded that the adoption of simulation-based educational strategies represents a significant advance in the teaching of neonatal endotracheal intubation, contributing not only to the technical improvement of professionals, but above all to the safety and quality of care provided to newborns. Expanding the use of these methodologies, together with encouraging public policies and ongoing research, is fundamental to building a more efficient, equitable and patient-centered clinical practice.

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