

Original Publication

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Basics of Infant Conventional Mechanical Ventilation: An Interactive Animated Teaching Module

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Abstract

Introduction: While conventional mechanical ventilation is a common therapy in the neonatal intensive care unit (NICU), pediatric residents receive insufficient instruction. This stand-alone computer module provides an interactive method of learning basic infant pulmonary physiology and principles of mechanical ventilation. **Methods:** This module runs offline and is compatible with a variety of operating systems. Participants complete a six-question, case-based pretest. The seven-section instructional module is self-paced, narrated, animated, and interactive. Learners can repeat each section as needed. At the conclusion of the module, participants complete the same six-question test and receive feedback. In total, the module requires 15-20 minutes to complete. **Results:** The curriculum has been implemented at the beginning of the NICU rotation over a 2-year period within our pediatric residency program. Participants preferred this interactive module and had higher posttest scores when compared to a PowerPoint presentation. After 4 months, there was evidence of knowledge decay. **Discussion:** The interactive module is enjoyable, effective, and convenient. It engages participants in active learning and allows them to control the time and pace of their instruction. We have implemented the curriculum within our residency program and believe it would be useful for a variety of NICU health care providers.

Keywords

Infant, Lung, Neonate, Pulmonary, Neonatal, Ventilation, Respiration, Ventilator, Neonatal Intensive Care Unit

Appendices

- A. Principles of Infant Mechanical Ventilation
- B. Mechanical Ventilator Survey.docx

All appendices are peer reviewed as integral parts of the Original Publication.

Educational Objectives

By the end of this session, learners will be able to:

1. Distinguish between negative and positive pressure ventilation.
2. Describe how a newborn establishes functional residual capacity.
3. Describe the components of mean airway pressure.
4. Describe the components of minute ventilation.
5. Explain how to adjust mean airway pressure using a mechanical ventilator.
6. Explain how to adjust minute ventilation using a mechanical ventilator.
7. Describe the difference between a volume-controlled ventilator and a pressure-controlled ventilator.

Introduction

Mechanical ventilation is a common therapy in the neonatal intensive care unit (NICU). Between 10%-20% of all infants admitted to an NICU receive mechanical ventilation.¹ Developing proficiency in mechanical ventilation requires a significant amount of experience; however, program requirements for pediatric residency training have restricted the amount of intensive care exposure and limited the opportunities for residents to become comfortable with this skill.² Prior to developing this module, we conducted a survey among pediatric residents at the University of Michigan to assess self-perceived comfort managing infant mechanical ventilation. One-third of residents felt uncomfortable to very uncomfortable with their ability to manage a mechanical ventilator. Only 7% of residents reported that they were very comfortable managing

mechanical ventilation, and 14% were very satisfied with their mechanical ventilation education. This is consistent with data from a study of recent pediatric resident graduates that showed low scores on validated assessments of mechanical ventilation knowledge and case management.³ Insufficient training in mechanical ventilation is not limited to pediatric residency programs. Similar deficits in knowledge and self-perceived competence have been reported among internal medicine and emergency medicine residents.^{4,5}

In our residency program, didactic lectures given during NICU rotations were the primary instructional method for teaching the principles of mechanical ventilation. We recognized that this passive instructional method was not meeting our learners' needs and was not consistent with adult learning principles.⁶ Trainees frequently missed lectures because of scheduling conflicts, call schedules, duty-hour limits, and patient care activities. Those who attended lectures described them as difficult to understand and not engaging. Bedside teaching is more interactive and proximal to the patient encounter, but it requires access to suitable patients, can be impractical with the time demands of patient care during NICU rounds, and is ineffective if learners lack sufficient background knowledge.⁷ Although core textbooks cover pulmonary physiology and mechanical ventilation in exhaustive detail, the volume and complexity of information presented are not practical for independent reading during an NICU rotation.^{8,9} Virtual mechanical ventilation simulators are commercially available and provide the opportunity for immersive learning that supports adult learning; however, most are complex, assume an established understanding of pulmonary physiology, focus on adult pathology, and require users to purchase expensive equipment or software.¹⁰

This resource was developed to provide a readily available, interactive method for learning basic pulmonary physiology and management principles of mechanical ventilation for infants. Although the target learners are pediatric residents, the learning objectives and instructional material are appropriate for medical students, nursing students, and respiratory therapy students who perform clinical rotations in an NICU or pediatric intensive care setting. There are no similar teaching activities currently available in *MedEdPORTAL*.

Methods

This self-directed learning module was designed to allow residents to acquire basic content knowledge at their own pace so that attending-led bedside teaching could focus on strengthening and synthesizing knowledge. This is a clinical variation of the flipped classroom model.^{11,12} To enhance learning, the computer module included narration, animation, and interactive components allowing the learner to adjust ventilator parameters and see the effect on both mean airway pressure and minute ventilation.¹³ To further engage learners, self-assessments were included at the beginning and end of the module. Learning objectives, educational content, and assessment methods were developed by a team including content experts in neonatal mechanical ventilation, neonatal resuscitation, and instructional design. During the development stage, a self-directed, annotated PowerPoint presentation including the same instructional material without narration, animation, or interactive components was prepared as a possible alternative. Based on testing results and feedback from participants, the PowerPoint version was discontinued.

We recommend that learners use the computer module just before beginning the NICU rotation or during the first week of the rotation. This temporal connection increases the activity's relevance, helps learners make connections with their clinical experience, and provides additional motivation for mastering the concepts.¹⁴ The file is easily shared with residents via email or flash drive. If possible, preload the files on a computer accessible to residents in their workspace within the NICU. During the first day of the clinical rotation, include this expectation in your orientation to the NICU, and track progress during the first week. Inform residents that the module takes approximately 15-20 minutes to complete and can be interrupted and resumed if necessary.

The module is compatible with Windows and Apple operating systems and has been tested with a variety of internet browsers. To begin the module, launch the file *Basic Principles of Mechanical Ventilation.html* (contained in the zip folder in Appendix A) by double-clicking on the file name. If prompted, choose an

internet browser to open the file. The module uses an internet browser but does not require an active internet connection once the files have been downloaded.

The module begins with a pretest that includes six case-based questions with multiple-choice answers. Learners are not provided with the correct answers until they complete the instructional module and revisit the cases during the posttest. Learners advance through the module by clicking the NEXT or PREV button at the bottom of each screen. The narrated portion of each screen begins by pressing the triangular play button. Animated slides allow the learner to drag and drop items or adjust ventilator settings by clicking on the Adjust button followed by the up or down arrow.

The instructional portion of the module is divided into seven sections:

- Spontaneous versus mechanical ventilation.
- First breaths.
- Oxygenation and ventilation.
- Compliance.
- Pressure-control ventilators.
- Volume-control ventilators.
- Summative review.

A navigation pane is provided along the side to allow learners to view their progress and quickly return to previous sections as needed. Learners can exit the module if necessary and are offered the option to resume where they left. After completing the instructional content, learners are prompted to complete the posttest. The posttest presents the same six case-based questions as the pretest. Upon completion of the posttest, the learner's responses and percentage correct are displayed. Learners are required to answer five questions correctly to pass the posttest. Completing the entire module, including pre- and posttest questions, requires an average of 15-20 minutes. We created all images, graphics, and animations provided within the module.

We recommend that after completing the module, learners meet with an experienced clinician to review how important measurements (tidal volume, minute ventilation, mean airway pressure, peak inspiratory pressure, positive end expiratory pressure, and inspiratory time) and physiologic trends are displayed on the ventilator used in their own clinical setting. This review session allows learners to establish connections between the instructional material in the module and the ventilator they will use. Finally, we recommend distributing a learner satisfaction survey to assess the module's effectiveness. A sample survey is provided in Appendix B.

Results

The curriculum has been implemented at the beginning of the NICU rotation over a 2-year period within our pediatric residency program. During the initial development stage, 31 volunteer pediatric residents at the University of Michigan completed the interactive computer module and the self-directed PowerPoint presentation. When surveyed, all 31 residents preferred the interactive computer module. In addition, nearly all (30 out of 31) believed that the interactive module was more effective in teaching basic ventilator concepts and that it increased their confidence managing ventilators. Participating residents commented that the interactive module was enjoyable, effective, and convenient. In the free-comment and suggestion section of our postmodule survey, residents indicated they preferred the module's ease of accessibility compared with live lectures and found the animation, narration, and interactive components more effective than an annotated PowerPoint presentation. After the initial pilot, the pre- and posttest questions were edited for clarification based on participant feedback.

To further evaluate the effectiveness of the interactive module at increasing knowledge, a second group of volunteer residents ($N = 57$) was randomly assigned to receive the interactive computer module ($n = 30$) or the self-directed PowerPoint presentation ($n = 27$). Residents were asked to access their assignment on a shared computer file and complete the assigned module within the first week of their NICU rotation. Access to the assignment was electronically audited, and the amount of time spent with each assignment

was recorded. Most residents in both groups (20 out of 30 in the interactive group, 22 out of 27 in the PowerPoint group) accessed the assignment; all residents who accessed the assignment completed it. Pre- and postmodule test scores were compared between the groups (Table). There was no significant difference in premodule test scores between the groups, suggesting similar baseline knowledge. Postmodule test scores increased after the interactive computer module but did not change after the PowerPoint presentation. The difference in posttest scores between groups was statistically significant ($p < .01$). The average time spent using the interactive module was 17.8 minutes, compared to 6.7 minutes for the PowerPoint presentation.

Table. Median Pretest and Posttest Scores

Test	Interactive Computer Module	Self-Directed PowerPoint	p^a
Pretest	83% ^b	83% ^c	.62
Posttest	100% ^b	83% ^c	<.01
Follow-up (4 months)	83% ^d	66.5% ^e	.66

^aMann-Whitney U test.

^b $N = 20$.

^c $N = 22$.

^d $N = 10$.

^e $N = 12$.

Four months after finishing their NICU rotation, residents were asked to complete the same knowledge posttest. Although a large number of residents were lost to follow-up and there was no significant difference between groups, the scores suggested that both groups experienced knowledge decay.

Discussion

Mechanical ventilation is a common but technically challenging therapy that requires extensive education and experience to develop proficiency. This interactive computer module was developed to address a deficit in pediatric resident education. The instructional material focuses on respiratory physiology and basic concepts of conventional mechanical ventilation. In comparison to traditional didactic lectures, the computer module is brief, self-paced, and easily accessible and can be used whenever the pediatric resident has available time. These attributes are consistent with principles of adult learning and medical education.^{6,14}

Residents preferred the interactive computer module compared to an annotated PowerPoint presentation with the same content. After using the module, they perceived an increase in self-confidence and had higher scores on a posttraining knowledge assessment. This demonstrates that self-directed learning is a feasible instructional method for learning this complex material if residents are provided with an appropriate resource. Although the self-directed PowerPoint version was also accessible, we speculate that it was ineffective because it failed to engage learners, as demonstrated by the short amount of time our residents spent with the activity. As a result, we discontinued the PowerPoint version and have focused our efforts on implementing the interactive module.

We found that residents required several reminders to access the module within the first week of their NICU rotation. Once residents accessed the module, they all completed it without difficulty. To promote intrinsic motivation, we recommend distributing the module to residents with an introductory message that explains the objectives, asks them to reflect on their current knowledge about mechanical ventilation, and describes instructor expectations just before their NICU rotation begins.¹⁵⁻¹⁷

Mechanical ventilation knowledge scores increased immediately after completing the instructional module, but there was evidence of knowledge decay 4 months after completing the NICU rotation. This is similar to the rapid decay of pediatric resuscitation knowledge demonstrated by trainees who rarely use the knowledge after the initial training.¹⁸ Unfortunately, a large number of participants were lost to follow-up, and we were not able to control for resident training level to determine if knowledge decay was greater among more junior residents or those who had completed fewer ICU rotations. Repetition is important for

retention of cognitive skills over extended periods of nonuse.¹⁹ Based on our experience and the potentially long interval between NICU rotations, we recommend distributing the computer module before each NICU rotation to provide opportunities for repetition.

The instructional material in this module establishes fundamental concepts. It is not intended to be a comprehensive curriculum leading to proficiency in mechanical ventilation for infants. Developing proficiency likely requires multiple instructional methods, including self-directed learning, simulation, and practical hands-on guidance from experienced clinical faculty. Once the fundamental concepts are well established, we suggest that learners supplement their knowledge with a more complex ventilator simulator.²⁰ The benefits of technology-enhanced ventilator simulation include the potential for distributed practice, interactivity, and clinical variation.²¹ Given the differences in ventilator design, a hands-on “knobology” tutorial with the ventilator actually used at your institution may improve resident self-confidence.²² Although an intensive mechanical ventilation boot camp is ideal, the resources required to develop and maintain such a program are prohibitive for most institutions.²³

We have implemented this interactive computer module over a 2-year period in our pediatric residency program. Participants have described the module as enjoyable, effective, and convenient. It engages participants in active learning and allows them to control the time and pace of their instruction. By integrating this module with other instructional methodologies, including simulation and bedside education, we believe that residents can develop proficiency in mechanical ventilation. Ultimately, this may improve long-term outcomes for preterm infants.²⁴ Although the module was originally developed for pediatric residents, the fundamental principles are relevant to students and other health care providers responsible for managing critically ill infants in the neonatal and pediatric intensive care units.

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Informed Consent

All identifiable persons in this resource have granted their permission.

Ethical Approval

Reported as not applicable.

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