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Impact of Longitudinal Mechanical Ventilation Curriculum on Decay of Knowledge

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ABSTRACT

Background: Prior evidence suggests that critical care trainees and attendings may have trouble recognizing common, potentially life-threatening mechanical ventilation (MV) waveform asynchronies. Although dedicated workshops may improve knowledge in MV, this knowledge may be prone to decay over time. Longitudinal, preceptorial-based curriculums may prevent this decay in knowledge.

Objective: To determine if the addition of a year-long, longitudinal MV preceptorial curriculum to a two-part, small-group, simulation-based education block curriculum reduces decay in MV knowledge compared with the education block curriculum alone.

Methods: This was a multicenter prospective cohort study including 123 first-year fellows from 12 critical care fellowship programs who completed a two-part simulation-based education block (control) after the first and sixth months of fellowship. Fellows from one of these programs also participated in a year-long preceptorial curriculum (intervention). MV waveform examination scores over time during fellowship were compared between control versus intervention groups.

Results: Mean test scores increased for both control and intervention groups after the education block courses at Months 1 and 6 of fellowship. Mean (standard deviation) test scores at Month 12 were higher for the intervention group than the control group (89.3 [14.8] vs. 47.7 [21.4]; $P < 0.0001$). Between 6 months and 3 years of fellowship,

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there was a significant decay in test scores for the control group (slope estimate [standard error], −13.4 [1.7]; $P < 0.0001$). However, there was no significant decay in test scores for the intervention group (slope estimate, −2.0 [4.7]; $P = 0.67$; difference in slope estimates, 11.4 [5.0]; $P = 0.02$).

Conclusion: The ability of critical care fellows to identify MV waveform asynchronies declines over fellowship training, despite a dedicated two-part, simulation-based MV educational curriculum. The addition of an MV preceptorial course decreased decay of MV knowledge over the course of fellowship training.

Keywords:
education; training; critical care; simulation

Management of mechanical ventilation (MV) is a fundamental skill required of all critical care (CC) practitioners and is considered a core competency for CC fellowship programs (1). Despite this, prior studies indicate that medical trainees may lack comfort in managing MV, and even CC fellows and attendings may have trouble recognizing common, potentially life-threatening waveform asynchronies (2–4). No universally adopted MV curriculum currently exists for CC training, and prior evidence suggests significant heterogeneity within MV education, as well as learner dissatisfaction with their MV training (3). As a result, there is a clear need for CC training programs to develop and implement dedicated MV learning objectives and educational strategies that bridge the gap between the current skill level of intensivists who manage MV with the expectations required for mastery of the subject.

A recent single-center prospective cohort study demonstrated that the use of a simulation-based mastery learning model significantly improved medical resident mechanical ventilator management knowledge (5). Our group recently published a multicenter prospective cohort study, which demonstrated that a MV curriculum focused on ventilator physiology and waveform analysis improved the ability of CC fellows to recognize common and potentially dangerous waveform abnormalities (6). Despite the improvement in fellows' knowledge, the study suggested that knowledge gained from the 3-day interactive summer portion decayed over time, only to improve to the highest point after a 2-day refresher during part two of the course. Therefore, we sought to determine in this study if the addition of a year-long, longitudinal, one-on-one MV preceptorial curriculum to our existing education block curriculum (intervention group) reduces decay in MV waveform interpretation knowledge compared with the education block curriculum alone (control group).

METHODS

We performed a multicenter prospective cohort study including fellows from 12 CC fellowship programs located in the mid-Atlantic region of the United States who completed a MV waveform examination between July 2016 and June 2021. First-year fellows from these programs participated in the education block as part of the DC–Baltimore Critical Care Educational Consortium for fellows (7). In addition to the MV education block, first-year fellows from one program also participated in the year-long preceptorial course from August until June of the respective fellowship year between August 2016 and June 2019. This program was the only site that had historically implemented the preceptorial as part of their educational curriculum before 2016 and was thus chosen as the intervention site. Fellows included in the study belonged to either critical care medicine (CCM), pulmonary CCM, or combined emergency medicine/CCM or neuro/CCM fellowship programs. This study was deemed exempt from institutional review board review by all participating institutions.

Mechanical Ventilation Education Block Curriculum

Details of the two-part MV education block curriculum have been previously described (6, 7), and further description can be found in the data supplement. Part I of the course focused on fundamental concepts of MV and was 3 days in length, taking place in July during orientation of the first year of fellowship. Part II of the course served as a review of part I and introduced more advanced topics in MV. Part II lasted 2 days and took place 6 months later, in January of the first year of fellowship.

MV Preceptorial Curriculum

In addition to participating in the education block, first-year fellows from one of the participating programs took part in the preceptorial course during the same academic year (intervention group). This course was designed to achieve mastery of various fundamental, yet complex, topics in MV. Preceptorials, based on the Oxford model of teaching (8), consisted of regularly scheduled interactive learning sessions with an expert preceptor in MV. These preceptorials were structured in a "flipped classroom" format, where learners were asked to prepare coursework before the session and then use the meeting time to teach the content back to the expert. Content was focused on various aspects of ventilator physiology and waveform analysis (*see* Table E1 in the data supplement for course content). Throughout the year, fellows arranged 90-minute one-on-one meetings with the course preceptor (B.W.L.) for each chapter (in person or via video conference). Before each preceptorial meeting, fellows independently prepared by completing an assigned checklist for each chapter. This checklist consisted of core reading assignments (including review articles and primary research studies), review of specifically assigned concepts, and submission of deidentified waveform photographs related to various assigned clinical scenarios (Table E2). Fellows were provided with a worksheet that included several questions related to each chapter's principal topic. These questions emphasized equations, clinical applications of complex patient–ventilator physiology, and waveform analysis. During each meeting, fellows followed the worksheet outline, answering each question in an effort to teach the material back to the preceptor. If a fellow struggled with the material, the preceptor would provide clarification and further instruction; if a fellow could readily answer the prepared questions, the preceptor would ask additional, higher-level questions, to determine the fellow's level of mastery. After the meeting, the fellow was assigned a score for each concept on a scale of 1 to 7, with higher scores indicating greater mastery of the subject matter. The average score for each concept was calculated to compute an overall score, with a minimum score of 5 required to advance to the next chapter (Table E3). Fellows who failed to achieve the minimum score were required to repeat the preceptorial meeting, generally focusing on the identified areas of deficiency. At the end of the fellowship year, after successfully completing all eight chapters of the course, fellows underwent a final assessment consisting of an oral examination evaluating the fellow's mastery of key concepts from the preceptorial course. Fellows were evaluated by two or three neutral expert examiners (not including their preceptor for the course) who had previously completed the preceptorial course in prior years. Fellows were again given a final score from 1 to 7, with a minimum score of 5 required to pass. When scoring the final exam, the examiners were asked to imagine how they would feel if the learner being tested were to be the clinician in charge of caring for their loved one's (e.g., a spouse's) ventilator in the intensive care unit (ICU) as the benchmark for competency. For fluency, the examiners were asked to imagine how they would feel if the learner being tested were to be the attending in charge of their loved one (e.g., an offspring) who is a first-year critical care fellow. After the exam, examiners met in a conference call to agree on the final score. The call aimed to clarify the difference between fluent and competent, and, if there were differences in individual examiner's initial impressions, they were discussed until consensus achieved.

Waveform Test

Details regarding the design and content of the MV waveform test have been previously published (6). In summary, the waveform test, developed by one of the authors (B.W.L.), consisted of five pictures, each depicting pressure–time and flow–time scalars representing common waveform asynchronies that may result in adverse clinical outcomes based on available evidence (9). These asynchronies include ineffective triggering, auto-triggering, flow starvation, premature cycling, delayed cycling, and signs of auto–positive end-expiratory pressure. Examinees were asked to identify the type of asynchrony and potential clinical consequences of this asynchrony from a list of potential answers. The test takes approximately 10 minutes to complete and is scored on a scale of 0–100, with each question weighted evenly. Each waveform examination was independently scored by at least two of the authors (B.W.L., M.A., and N.S.), and the scores were checked for interrater reliability. Any discrepancy was resolved by consensus. Additional details regarding the development of the final exam are presented in the data supplement.

The study subjects took the waveform test at the following time points: *1*) as a pretest before part I; *2*) posttest at the end of part I; *3*) pretest before part II; *4*) as a posttest at the end of part II; and *5*) at the end of each academic year on Months 12, 24, and 36 of fellowship training (*see* Figure 1). The content of the examination did not change; however, the order of the questions was changed each time, and the answers were not shared.

Study Outcomes

The primary outcome was the difference in waveform test scores over time between the control group (education block only) and the intervention group (education block plus preceptorial program).

Statistical Analysis

Continuous variables were summarized using mean and standard deviation (SD), and categorical variables were summarized using counts (%). Linear models were used to compare scores on waveform examinations between groups. A random subject effect was used to

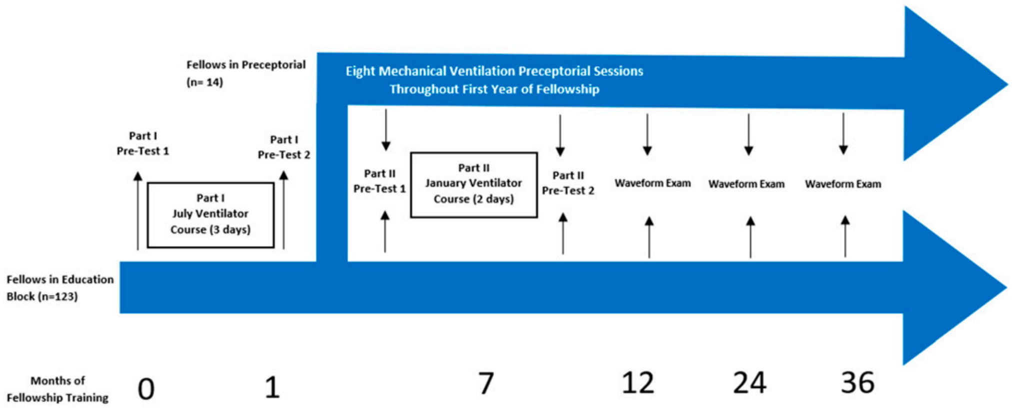

Figure 1. Flow diagram demonstrating the timing of education block courses and waveform testing. Fourteen fellows from one of these programs also participated in a year-long preceptorial curriculum in addition to the education block courses.

account for repeated measurements of individual subjects. Standard residual diagnostics were used to check model assumptions. SAS version 9.4 was used for all analyses. All reported *P* values are two sided.

RESULTS

Overall, 123 fellows from 12 fellowship programs were included. Sixty-six (54%) were in pulmonary CCM fellowship, and 57 (46%) were in a CCM program. A total of 109 fellows completed the education block alone (control group) and 14 completed both the education block and the preceptorial course (intervention group) (Table 1).

There was no significant difference between summer pretest scores for the control and intervention groups (mean [SD]: 18.1 [13.3] vs. 22.5 [17.4]; $P = 0.42$). After education block part I, mean posttest scores increased for both control (18.1 [13.3] to 47.3 [22.5]; $P < 0.0001$) and intervention groups (22.5 [17.4] to 59.3 [27.8]; $P < 0.0001$).

Compared with posttest scores after education block part I, the mean part II pretest scores significantly decreased for the control group ($P < 0.0001$) but not for the intervention group. Part II pretest

Table 1. Characteristics of fellowship training

	Education Block Only Fellows (Control)	Education Block Plus MV Preceptorial (Intervention)
Number of first-year fellows	109	14
Type of fellowship, *n* (%)		
PCCM	59 (54)	7 (50)
CCM*	50 (46)	7 (50)

Definition of abbreviations: CCM = critical care medicine; MV = mechanical ventilation; PCCM = pulmonary critical care medicine.
*This includes combined surgical/CCM, neuro/CCM, emergency medicine/CCM programs. In addition, fellows from the program participating in the MV preceptorial could further specialize after their initial year of CCM training.

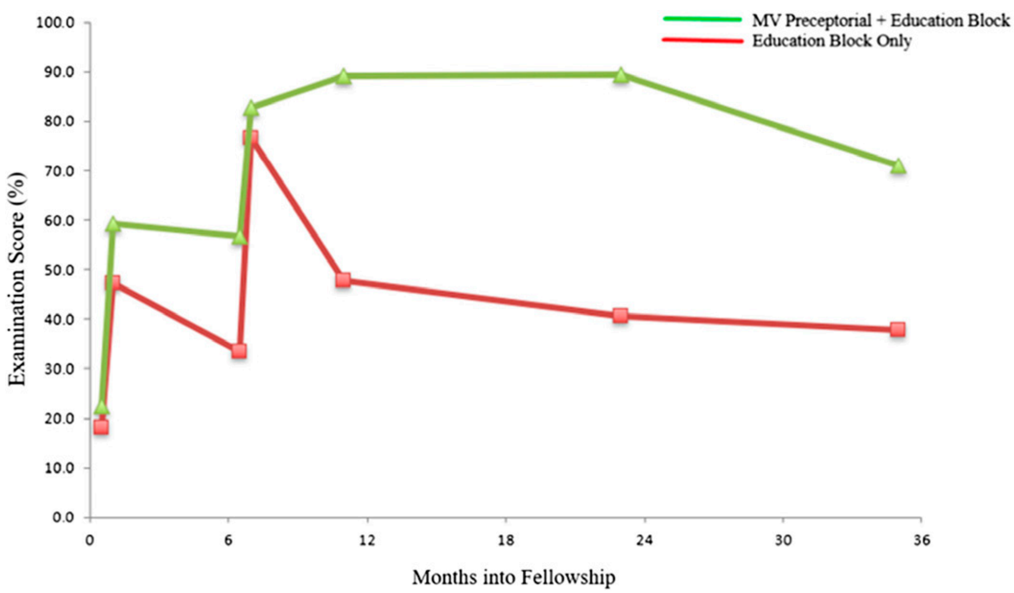

Figure 2. Longitudinal comparison of waveform examination scores between education block versus preceptorial block fellows over the course of fellowship training. Education block fellows demonstrated a significant decay in mechanical ventilation (MV) knowledge over the course of the fellowship, whereas preceptorial course fellows did not. Summer education block (SEB) pretest (control = 79; intervention $n = 11$), SEB posttest (control = 55; intervention $n = 8$), WEB pretest (control = 55; intervention $n = 11$), winter education block (WEB) posttest (control = 50; intervention $n = 11$), fellowship year 1 (FY1) inservice (control = 55; intervention $n = 11$), FY2 inservice (control = 44; intervention $n = 4$), FY3 (control = 27; intervention $n = 3$).

scores were higher for the intervention group than the control group (56.8 [26.4] vs. 33.5 [21.0]; $P = 0.0002$). Part II posttest scores significantly increased in both groups (mean [standard error] increase, 42.8 [3.2]; $P < 0.0001$ for control and 26.0 [6.8]; $P = 0.0002$ for intervention). However, there was no significant difference in part II posttest scores between the two groups ($P = 0.25$) (Figure 2).

Mean test scores at Month 12 of fellowship training significantly decreased for the control group (47.7 [21.4] at 12 months vs. 76.7 [16.8] at end of education block part II; $P < 0.0001$) but did not change significantly for the intervention group (89.3 [14.8] at 12 months vs. 82.8 [11.5] at end of education block part II; $P = 0.35$). Mean test scores at Month 12 were higher for the intervention group than the control group (89.3 [14.8] vs. 47.7 [21.4]; $P < 0.0001$).

We next fitted separate regression lines for test scores at time points between 6 months and 3 years of fellowship. There was a significant decay in test scores for the control group (slope estimate (standard error), −13.4 [1.7]; $P < 0.0001$). However, there was no significant decay in test scores for the intervention group (slope estimate, −2.0 [4.7]; $P = 0.67$; difference in slope estimates, 11.4 [5.0]; $P = 0.02$).

DISCUSSION

In this study, we demonstrate that knowledge of MV waveform analysis decays over the course of fellowship despite a dedicated, two-part, MV education curriculum. However, a longitudinal preceptorial course in the first year of fellowship reduces the rate of decay of MV waveform knowledge over the subsequent years of the fellowship. Our study adds to existing literature indicating the potential for medical knowledge to decay over time and expands this to the field of MV education during CC fellowship (10–12).

Prior studies have demonstrated the potential for significant decay in medical knowledge over the course of training, especially during dedicated research time (13, 14). Our study indicates that medical knowledge decays even during clinical portions of fellowship training, suggesting that traditional CC training consisting of ICU rotations, as well as bedside teaching and didactics, may not prevent decay of knowledge, particularly for complex topics such as MV. This concerning knowledge decay occurred despite a two-part intensive MV curriculum in July and January of the first fellowship year. Previous research based on algorithmic processes, such as advanced cardiac life support or pediatric resuscitation algorithms, has demonstrated the potential for knowledge decay months after taking dedicated courses (10, 15). Given the added complexities of MV waveform analysis, which integrates advanced cardiopulmonary physiology, context-based critical thinking, and a technical understanding of MV, it is not surprising that these findings extend beyond the field of algorithm-based processes (16). For instance, cognitive tasks requiring complex decision making and mental operations, such as management of MV, may be more susceptible to skill decay than physical tasks alone (17). More frequent, longitudinal education strategies, such as this preceptorial course, may be required to facilitate knowledge retention.

This preceptorial curriculum was designed to achieve mastery of various topics in MV, including waveform analysis. To achieve a standardized measure of fluency, the preceptorial course incorporates a variety of strategies related to the concept of deliberate practice, which refers to dedicated effort to enhance performance aspects in need of improvement (18). The process relies on identifying specific areas of improvement and engaging in expertly designed, repetitive practice to refine knowledge and skill. With expert oversight, the aim is to gradually improve performance, while providing constructive feedback for individualized, goal-oriented progression through the subject matter. This often involves frequent retesting and remediation. The MV preceptorial course incorporated each of these aspects of deliberate practice through frequent 90-minute sessions with an expert who critically evaluated the ability of the learner to articulate complex concepts in real time. Each session requires extensive preparation by the learner. At times, repeat sessions were necessary to achieve the minimum score required to progress to the next chapter. This type of spaced learning may promote a deeper understanding of the subject matter with the goal of fluency—the ability to easily and accurately articulate key concepts and field advanced questions without error. Notably, Ericsson and colleagues have postulated that deliberate practice may be difficult to incorporate in the work setting, an argument consistent with the findings of our study, indicating that reliance on ICU rotations and bedside teaching alone is insufficient to achieve mastery in MV waveform analysis (19). The time constraints and performance pressures of the work setting may limit a learner's ability to intellectually explore other methods of learning (20). Furthermore, prior studies have demonstrated that continuing medical education seminars or the duration of clinical experience alone does not result in meaningful benefits in clinical judgement or quality of care delivered by healthcare professionals, emphasizing the importance of the application of deliberate practice and the expert performance framework (21–23).

Limitations

This study has several limitations. The sample size of fellow examinations available for comparison at Fellowship Year 3 was small. Missing exam data prevented the full comparison of test scores for all 123 fellows at each time point. Although 12 fellowship programs were included in this study, only one fellowship program participated in the preceptorial course, leading to potential selection bias and limiting the ability to extrapolate the performance of these fellows to other fellowship programs. Both the education block and the preceptorial course covered MV topics beyond waveform recognition, including ventilator-associated lung injury, lung-protective strategies for acute respiratory distress syndrome, and liberation from MV. Our study does not determine the degree to which these educational strategies increase and promote retention of knowledge in these subjects, which should be a focus of future work. Despite the potential benefits, the combination of the education block and the preceptorial course requires a considerable number of educational resources. Fellowship programs may face a number of barriers to implementing such a curriculum, including time constraints, limited faculty expertise, and lack of simulation-based educational resources.

Conclusions

In summary, we have found that the ability of CC fellows to identify MV waveform asynchronies declines during fellowship, despite a dedicated two-part MV educational curriculum, suggesting that MV waveform mastery is difficult to achieve with traditional methods of MV education. However, the addition of a preceptorial course reduced decay of this knowledge over the course of fellowship training, albeit at the cost of significant time requirements and educator expertise. Given the critical need for MV waveform mastery, these findings support the urgent need to identify optimal educational strategies to achieve mastery and reduce decay of knowledge over the course of CC fellowship training.

Author disclosures are available with the text of this article at www.atsjournals.org.

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