ORIGINAL RESEARCH



# Creation of an International Interprofessional Simulation-enhanced Mechanical Ventilation Course

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## ABSTRACT

**Background:** Evidence shows poor adherence to strategies for reducing morbidity and mortality in intensive care unit (ICU) patients receiving mechanical ventilation globally. Best practice management relies on training all members of the interprofessional ICU team, each with complementary roles in patient management.

**Objectives:** To develop and evaluate a novel two-phase, train-the-trainer, interprofessional and multicultural "Best Practice Management of the Ventilated ICU Patient" multimodality, simulation-enhanced curriculum for Thai education leaders in critical care.

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**Methods:** In phase 1 (Oregon Health and Science University cohort), two groups of nine ICU nurses and one critical care physician representing experts in critical care and education from a large hospital system in Thailand participated in a weeklong, immersive course consisting of didactic, simulation, and in situ immersive sessions focused on best practice management of mechanically ventilated ICU patients, as well as training in our educational techniques. Outcomes were assessed with pre- and postcourse knowledge assessments and overall course evaluation. In phase 2 (Thai cohort), participants from phase 1 returned to Thailand and implemented a lower fidelity curriculum in two hospitals, using the same pre- and posttest knowledge assessment in 41 participants, before the onset of the coronavirus disease (COVID-19) 6 pandemic.

**Results:** In the Oregon Health and Science University cohort, the mean pretest knowledge score was 58.4 ± 13.2%, with a mean improvement to 82.5 ± 11.6% after completion of the course ($P$, 0.05). The greatest improvements were seen in respiratory physiology and advanced/disease-specific concepts, which demonstrated absolute improvements of 30.4% and 30.6%, respectively ($P < 0.05$). Participants had a high degree of satisfaction, with 90% rating the course as "excellent" and .90% reporting that the course "greatly improved" their understanding of best practices and comfort in managing mechanical ventilation. The Thai cohort had a mean baseline score of 45.4 ± 15.0% and a mean improvement to 70.3 ± 19.1% after training ($P < 0.05$). This cohort also saw the greatest improvement in respiratory physiology and advanced/disease-specific concepts, with 26.2% and 26.3% absolute improvements, respectively ($P < 0.05$).

**Conclusion:** A novel, two-phase, interprofessional, multicultural, simulation-enhanced train-the-trainer curriculum was feasible and effective in improving education in best practice management of mechanically ventilated patients and may be a useful model for improving the care of ICU patients across the world.

**Keywords:**
mechanical ventilation; interprofessional; simulation; curriculum; intensive care unit best practices

Mechanical ventilation (MV) is a necessary and critical part of life-supportive therapy for patients in the intensive care unit (ICU) but is associated with significant morbidity and mortality, related to both harm from MV itself (i.e., ventilator-induced lung injury) and the infectious, psychiatric, and neuromuscular sequelae of intubation, sedation, and immobility (1–3). How we manage patients on MV has significant and direct impacts on patient outcomes as well as hospital costs (4–6). This is probably most clearly demonstrated in acute respiratory distress syndrome (ARDS), for which the use of lower tidal volume, pressure-limited strategies has consistently been shown to reduce patient mortality (5, 7, 8). Similarly, significant evidence exists supporting other best practices, including the use of lower tidal volume strategies for patients without ARDS (9–11), the early use of prone positioning for patients with moderate/

severe ARDS (12), protocolized extubation protocols (13), and implementation of the ABCDEF bundle (assess, prevent, and manage pain; both spontaneous awakening trials and spontaneous breathing trials; choice of analgesia and sedation; delirium assessment, prevention, and management; early mobility and exercise; and family engagement and empowerment) (3, 14, 15), aimed at decreasing ventilator-associated pneumonia (VAP) and neuromuscular weakness.

However, despite extensive evidence supporting these best practices, multiple studies have shown low adherence to these strategies (7–9, 16). In 2016, more than a decade after the publication of the Acute Respiratory Distress Syndrome Network ARMA (Prospective, Randomized, Multi-Center Trial of 12 ml/kg vs. 6 ml/kg Tidal Volume Positive Pressure Ventilation for Treatment of Acute Lung Injury and Acute Respiratory Distress Syndrome) trial (5), Bellani and colleagues demonstrated that across 50 countries around the world, ARDS still often goes unrecognized, and they showed poor adherence to low–tidal volume ventilator strategies (8). Multiple studies have identified barriers to adherence to best practice strategies for ventilated patients, including knowledge deficits among both nursing and physician members of the interprofessional team and failure to translate recommendations to bedside care (17–19). In the ICU, MV is managed by an interprofessional team consisting of physicians, nurses, and, in some areas of the world, respiratory therapists (RTs), each with distinct and complementary roles in managing patients receiving MV. Although healthcare education has historically been siloed, with physicians, nurses, and respiratory therapy students and trainees learning separately, in recent years there has been a greater interest in and emphasis on interprofessional education and training, particularly in the ICU (20–23). In addition, simulation-enhanced curricula have been shown to improve participant knowledge and applied skills (24–29). Simulation has gained a larger role in healthcare training and education, allowing deliberate practice in a patient-safe environment and bridging the gap between theory and practical application (30, 31). However, the broad use of simulation is time, cost, and resource limited both in the United States and around the world.

The objectives of our study were to develop an intensive, multimodality educational curriculum to improve participants' understanding of key best practices in the management of mechanically ventilated ICU patients and to train physician and nurse leaders in our educational techniques to then translate this curriculum into an effective, lower fidelity curriculum in their home institutions in Thailand. As part of an ongoing collaboration between Oregon Health and Science University (OHSU) and Bangkok Dusit Medical Services (BDMS) in Thailand, we adapted our high-fidelity simulation-enhanced MV curriculum and created a five-day "Best Practice Management of the Ventilated ICU Patient" course. This immersive train-the-trainer course combined didactics, simulation, and *in situ* experiences to train physician and nurse leaders in critical care, simulation, and education in best practices and educational strategies, which were then brought back and implemented in their hospital network in Thailand.

## METHODS

Our Best Practice Care of the Mechanically Ventilated Patient course was born out of an ongoing collaboration starting in 2016 between OHSU and BDMS, a private health system in Southeast Asia, comprising 49 hospitals across Thailand and Cambodia. As part of this ongoing collaboration, OHSU has been using a train-the-trainer model for best practices in simulation education, with a special emphasis on critical care. Our simulation-enhanced MV curriculum was developed with physician, RT, ICU nurse leadership, and simulation expert stakeholders and focused on evidence-supported best practices, including the use of lower, lung-protective tidal volumes, early recognition of ARDS (using the 2012 Berlin definition [32]), use of spontaneous breathing trials, readiness assessment for extubation, and VAP prevention (5, 13, 16, 33).

In addition to a literature review identifying evidence-supported best practices in MV, an on-site needs assessment was performed across BDMS hospitals by physician and nurse members of the study team by direct observation of ICU work flow in Thailand (J.A.G., A.S.R.-T., N.P., and N.C.). We identified knowledge deficits in best practice management, such as low adherence to lower tidal volumes and daily spontaneous breathing trials, and OHSU and BDMS leaders reached a collaborative recommendation for additional training in the specifics of best practices surrounding the care of mechanically ventilated ICU patients, leading to the development of this critical care best practices course. Our on-site needs assessment also identified significant cultural differences in practices and role responsibilities in managing MV. Notably, and in contrast to the United States and Canada, RTs are not a part of the ICU care team in Thailand, and their role in respiratory care and ventilator management is filled by physician (ventilator setup/initiation, management, ventilator discontinuation) and nurse (suctioning, oral care, titration of oxygenation, ventilator management, troubleshooting of alarms) members of the ICU team. We thus adapted our curriculum to include immersive training for ICU nurses not only in VAP prevention but also in hands-on ventilator management, waveform interpretation, and troubleshooting.

### Curriculum Overview/Objectives

The broad educational goal of the curriculum was to provide an interprofessional ICU team with training in both the principles and practical, hands-on application of evidence-supported best practices covering all aspects of the management of mechanically ventilated ICU patients. The course best practice management included prevention of VAP, neuromuscular weakness, cognitive/psychiatric complications of MV via the ABCDEF bundle (14, 15), as well as 10 core concepts aimed at minimizing morbidity and mortality from MV itself, grouped into three major subject areas:

1. Basics
   - Ventilator initiation
   - Mode basics
   - Liberation from MV
   - Minimizing ventilator-induced lung injury
2. Respiratory physiology
   - Ventilator waveforms
   - Gas exchange
   - Mechanics and maneuvers
3. Advanced/disease specific
   - Management of ARDS
   - Ventilation in obstructive lung disease
   - Ventilator emergencies and troubleshooting

In the first phase of the curriculum (OHSU cohort), two groups of nine nurses and one physician from BDMS traveled to

| | Monday | Tuesday | Wednesday | Thursday | Friday |
|---|---|---|---|---|---|
| AM | **Initial Knowledge Assessment <Completed>** | ***In Situ* Experience:**<br><br>**Group A** – ICU RN shadow experience<br><br>**Group B** – ICU RT shadow experience<br><br>**Group C** – ICU rounds | ***In Situ* Experience:**<br><br>**Group B** – ICU RN shadow experience<br><br>**Group C** – ICU RT shadow experience<br><br>**Group A** – ICU rounds | ***In Situ* Experience:**<br><br>**Group C** – ICU RN shadow experience<br><br>**Group A** – ICU RT shadow experience<br><br>**Group B** – ICU rounds | **DIDACTICS:**<br>-Recognizing and managing ventilator asynchrony.<br>-Advanced waveforms |
| | **Welcome** | | | | **SIMULATION:**<br><br>Unknown/wild card/ Ventilator emergency cases |
| | **DIDACTICS:**<br>Introduction to ICU best practices.<br>____________<br>**DIDACTICS:**<br>Introduction to the ABCDEF Bundle | | | | |
| PM | **DIDACTICS**:<br>Initiation of ventilation, basic ventilator modes and basic lung mechanics | **DIDACTICS:**<br>Ventilator induced lung injury 1.0, ventilator alarms, ventilation liberation | **DIDACTICS:**<br>Ventilation for ARDS, ventilator induced lung injury 2.0, hypoxemia | **DIDACTICS:**<br>Ventilation in obstructive lung disease, advanced ventilator waveforms | **Discussion / Q&A** |
| | **SIMULATION:**<br>**Normal lung case**<br><br>-Ventilator initiation<br>-Basic waveforms and maneuvers<br>-Measurement and interpretation of peak and plateau pressure | **SIMULATION:**<br>**Acute emergency #1; Vent Liberation**<br>- Using peak/plateau measurements to understand physiology<br>-Assessing readiness for extubation<br>-SAT/SBT<br>-Extubation screen | **SIMULATION:**<br>**ARDS case**<br>- Recognition of ARDS<br>-Minimizing lung injury<br>-Strategies for hypoxemia<br>-Strategies for hypercapnia | **SIMULATION:**<br>**Obstructive Case**<br><br>-Advanced waveforms/maneuvers<br>-Recognizing/managing air trapping and autopeep<br>-Advanced strategies for hypercapnia, dead space | Course Evaluation |
| | | | | | **Final Knowledge Assessment** |

**Figure 1.** Overview of Oregon Health and Science University on-site curriculum. Didactic sessions (in blue) consisted of one-hour slide presentations on core topics, taught by authors S.A.N. and J.A.G., followed by a brief Q&A session. Three-hour high-fidelity simulation sessions (in green) reinforced these core topics with deliberate practice of applied skills and structured debriefing. For the *in situ* experiences (in yellow), the cohort was split into three groups (A, B, and C) for a direct shadowing experience with a bedside intensive care unit (ICU) nurse (RN), an ICU RT, or the interprofessional ICU team for daily rounds. ABCDEF = assess, prevent, and manage pain; both spontaneous awakening trials and spontaneous breathing trials; choice of analgesia and sedation; delirium assessment, prevention, and management; early mobility and exercise; and family engagement and empowerment; ARDS = acute respiratory distress syndrome; Q&A = question-and-answer; RN = registered nurse; RT = respiratory therapist; SAT = spontaneous awakening trial; SBT = spontaneous breathing trial.

OHSU for a five-day train-the-trainer course including elements of didactic lectures, hands-on high-fidelity simulation, and immersive *in situ* experiences in our adult ICUs (Figure 1). Each element of the didactic lectures was deliberately incorporated in both simulation and the *in situ* experiences to reinforce theory with hands-on demonstration and practice. For example, implementation of the ABCDEF bundle, aimed at preventing VAP and the neuromuscular, cognitive, and psychiatric complications of MV, was reinforced using *in situ* 1:1 shadowing experiences with a bedside ICU registered nurse or ICU RT, while identification and management of potential ventilator-induced lung injury (or ventilator emergencies) were trained in multiple high-fidelity simulation sessions. We incorporated stepwise learning objectives, where the lessons from didactics were immediately applied to high-fidelity simulation scenarios, building from basic to more advanced topics. The course was interprofessional, with nurse and physician participants working together, mimicking their real-life clinical roles and collaboration.

### Didactics

All didactic lectures were 50-minute sessions with 10-minute question-and-answer sessions and were led by two pulmonary critical care physicians (S.A.N. and J.A.G.).

### Simulation

All simulation sessions were conducted in dedicated OHSU simulation space using the HAL S3201 advanced, interactive mannequin (Gaumard Scientific), capable of simulating a wide range of respiratory physiologies and patient/ventilator interactions, and the Hamilton G5 Ventilator (Hamilton Medical). Note that this model of ventilator is similar to that used in many BDMS hospitals for routine critical care management. All simulation sessions were coled by a pulmonary critical care physician (S.A.N.) and a dedicated RT. Each session lasted three hours and incorporated chest imaging and blood gases into clinical scenarios on the basis of the day's learning objectives, with structured debriefing after each scenario. Simulation was set up as a group activity with 10 learners, with 2 participants at a time taking lead and switching after each debrief and question-and-answer session. Each simulation was iterative, with all members participating and demonstrating hands-on skills, such as checking plateau pressure, and included multiple built-in minidebriefs throughout to ensure that concepts were learned. Because of varying degrees of English proficiency, we ensured that there was one expert member to help translate any difficult concepts and facilitate good two-way communication during the sessions and debriefs.

Using an intubated and mechanically ventilated interactive mannequin, participants were led through clinical vignettes and asked to initiate lung-protective MV, identify waveforms, perform ventilator maneuvers, identify when a patient met criteria for ARDS (using chest imaging, blood gas values, and clinical vignette details), troubleshoot emergency conditions, and determine readiness for extubation. The mannequin was used to simulate a wide range of respiratory physiologies, including normal lungs, ARDS, and airflow obstruction from severe obstructive lung disease to mainstem intubation, as well as displaying continuous vital-sign changes in hemodynamics and $O_2$ saturation, to enhance the fidelity of the simulation.

### *In Situ* Experiences

The *in situ* experiences were developed collaboratively by physician, nurse, and RT members of our team to reinforce key elements of best practice management from didactics and simulation sessions. For these, participants were split into three groups and rotated daily through three four-hour blocks (8 A.M. to 12 P.M.), with all participants rotating through each of three experiences:

1. ICU nurse shadowing: Participants reviewed nursing care plans, clinical practice guidelines, and endotracheal tube care policies and observed the performance of elements of the ABCDEF bundle, including collaborating with respiratory therapy for sedation hold and spontaneous breathing trials.
2. ICU RT shadowing: Participants reviewed respiratory therapy protocols and shadowed ICU RTs in setting up mechanical ventilators, performing regular ventilator checks and patient measurements, performing and evaluating spontaneous breathing trials and extubation screening, as well as adjusting

ventilator settings in response to physician orders or changing patient physiology.

3. Interprofessional ICU rounds: Participants were able to join interprofessional ICU rounds in one of OHSU's four adult ICUs, highlighting the knowledge sharing, communication, and shared responsibility among physicians, nurses, RTs, and pharmacists in managing ICU patients receiving MV. In addition, participants reviewed OHSU's MV provider order sets.

### Train-the-Trainer Educational Training

Participants in the OHSU course were physician and nurse leaders in critical care, simulation, and education at BDMS who would then go on to develop and lead the BDMS/Thailand course. This cohort not only participated in our curriculum as content learners experiencing the multimodality curriculum directly but also trained in our educational methods. Throughout the week, participants had progressive opportunities to lead training themselves, from teaching basic concepts and hands-on ventilator skills to debriefing scenarios, with members taking turns leading their cohort and receiving feedback on their teaching from OHSU study leaders.

### BDMS/Thailand Cohort

In phase 2, the participants from the original OHSU cohort, led by Dr. Pongparit and Nurse Charoensri, returned to Thailand and implemented focused training across two BDMS hospitals for a multidisciplinary group of ICU and emergency bedside nurses, of varying degrees of experience. This cohort of Thai nurses (the Thai cohort) participated in five didactic sessions paired with two-hour lower fidelity, hands-on simulation sessions. The didactic lectures included the same slide sets used for the OHSU-based training, translated into Thai, and were given in person and by live stream across two hospitals. These didactics were paired with a series of lower fidelity simulation sessions using a range of "lungs," including a simple two-balloon model used to demonstrate the effect of ventilation on lungs with areas of different compliance as well as more complex commercial test lungs (SunMed Test Lung [SunMed]; Dräger SelfTestLung [Drägerwerk AG and Co., KGaA]) and *ex vivo* pig lungs. These simulation sessions used a wide range of mechanical ventilators used in the ICU and the emergency department, and for transport across BDMS, including the Puritan Bennett 840 and 980 ventilators (Medtronic), the Hamilton S1 and C6 ventilators (Hamilton Medical), and the Dräger Carina transport ventilator (Drägerwerk AG and Co., KGaA). Using the mechanically ventilated simulation lungs, Thai cohort participants underwent hands-on training followed by demonstration of key skills, including performing ventilator mode changes, performing ventilator maneuvers, and interpreting waveforms and maneuvers. Participants were then led through clinical vignettes that included chest imaging and blood gases and asked to initiate lung-protective MV, interpret waveforms and maneuvers, recognize when a patient met clinical criteria for ARDS and respond with appropriate ventilator changes, determine readiness for extubation, and respond to ventilator emergencies, such as pneumothorax. Training videos of these hands-on MV-related skills, modeled by the instructors, were also created as part of an educational resource bank for future use. Full implementation of the curriculum across BDMS hospitals was halted prematurely because of the onset of the coronavirus disease (COVID-19) pandemic in March 2020.

### Outcomes Assessment

All participants in the course, from both cohorts, underwent pre- and postcourse knowledge assessments, using our validated test comprising 33 multiple-choice questions (34), which was translated into Thai by a member of the study team (M.S.) and administered with both English and Thai text. The pretest was taken before the start of training, and the posttest was given after completion of the final day of the training. Data presented here represent the 19 participants in the OHSU cohort who completed the pre- and posttest assessments and the 41 Thai participants who completed training and both pre-/posttest assessments before the COVID-19–related pause.

Pre-/posttest knowledge was analyzed using a paired *t* test for each participant, with *P* values $<0.05$ considered to indicate statistical significance using Prism (GraphPad Software). Results are expressed as mean ± standard deviation. Test results were analyzed both as a total score and by core concepts, grouped into the three major subject areas (basics, physiology, and advanced/disease specific). In addition, all participants in the OHSU cohort were given a final course assessment to evaluate the impact and quality of the course. Participants answered four questions related to the impact of the course on their understanding of best practice management of patients receiving MV, rated on a five-point Likert scale from "greatly decreased" to "greatly increased," as well as seven questions rating of the quality and usefulness of the different elements of the course to the learning objectives, assessed using a five-point Likert scale from "very poor" to "excellent."

## RESULTS

### Phase 1: OHSU Cohort (Train the Trainer)

Twenty participants, representing physician and nursing leaders in ICU, education, and simulation, participated in our five-day on-site curriculum at OHSU. Nineteen participants completed the baseline, pretest knowledge assessment, and 20 participants completed the posttest knowledge assessment. All participants completed the final evaluation of the course.

The baseline knowledge assessment showed an initial mean overall score of 58.4 ± 13.2%, with scores ranging from 39.4% to 87.9%. As seen in Figure 2A, the posttest knowledge assessment, given after completion of the course, demonstrated a mean score of 82.5 ± 11.6%, a 24.1% absolute improvement versus the baseline score ($P < 0.001$). All but one participant showed improvement, with maximum improvement of 42.2%. The two physician members of the group, who had significantly greater prior ventilator training and experience, scored higher on the baseline assessment, with a mean pretest score of 83.5 ± 6.4% versus 55.4 ± 10.0% for nurse participants.

When broken down by major subject area, the pretest assessment revealed that participants had the strongest baseline knowledge in basic ventilator concepts, with an average score of 64.7 ± 13.4%, followed by physiology at 52.1 ± 16.9% and then advanced/disease-specific topics with an average score of 50.7 ± 16.9% (Figure 2B). The posttest assessment demonstrated significant improvement in all three major subject areas after completion of the course, with the greatest improvements in the advanced/disease-specific area at 30.6% and physiology at 30.4%, followed by basic concepts at 22.1% ($P < 0.01$). There was a statistically significant improvement between pre- and posttest scores in each of the 10 core concepts, with the largest improvements seen in mode basics (49.1 ± 34.0% vs.

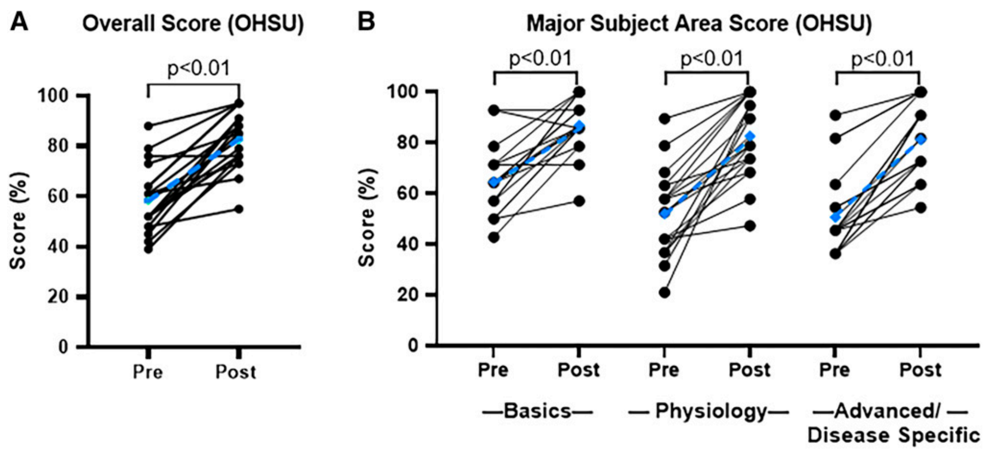


**Figure 2.** OHSU cohort knowledge assessment: results from a 33-question knowledge assessment completed before and after participation in our course ($n = 19$ participants). (*A*) Overall scores of participants increased from a mean of 58.4 ± 13.2% to 82.5 ± 11.6% after completion of the course ($P < 0.01$). (*B*) The greatest improvements were seen in the major subject areas of respiratory physiology (from 52.1 ± 16.9% to 82.5 ± 15.7%) and advanced/disease specific (from 50.7 ± 16.9% to 81.3 ± 14.7%), followed by basics (from 64.7 ± 13.4% to 86.8 ± 10.7%) ($P < 0.01$). Pre- and posttest scores were compared using a paired *t* test. Blue dashed line denotes mean. OHSU = Oregon Health and Science University.

80.7 ± 20.2%), ventilator emergencies/troubleshooting (48.7 ± 25.7% vs. 78.9 ± 19.1%), ventilation in obstructive lung disease (44.7 ± 17.8% vs. 85.5 ± 19.2%), and waveform interpretation (47.4 ± 25.1% vs. 94.7 ± 9.0%) ($P \leqslant 0.001$ for all), areas with lower baseline knowledge (*see* Table E1 in the data supplement).

### Assessment of Course Elements and Impact

As seen in Figures 3A and 3B, when asked to evaluate the course, OHSU cohort participants rated the course highly, with 100% rating it "very good" or "excellent." Participants particularly praised the utility of the RT observational/rounding activity and the pairing of didactics with simulation to reinforce core concepts. All participants reported that participating in the curriculum greatly improved their comfort in managing ventilation, and 90% believed that the course greatly improved management of ARDS, obstructive disease, and overall best practice patient management.

### Phase 2: BDMS/Thailand Cohort

Forty-one participants, all emergency and critical care nurses from two hospitals within the BDMS system, participated in an on-site curriculum and completed the baseline and posttest knowledge assessments before the onset of COVID-19.

As seen in Figure 4A, the baseline knowledge test showed an initial mean score of 45.4 ± 14.8%, with scores ranging from 24.1% to 90.9%. The mean posttest score was 70.1 ± 17.8%, a 24.7% absolute improvement from baseline ($P < 0.001$) (Figure 4B). As with the OHSU cohort, Thai participants had the highest baseline knowledge in ventilator basics (scoring 49.7 ± 17.6%), followed by physiology (44.8 ± 19.2%) and advanced/disease-specific concepts (34.2 ± 17.6%). There were significant improvements in all three areas after ventilator education, with mean absolute improvements of 25.0%, 26.2%, and 26.3%, respectively. Similar to the OHSU cohort, the greatest

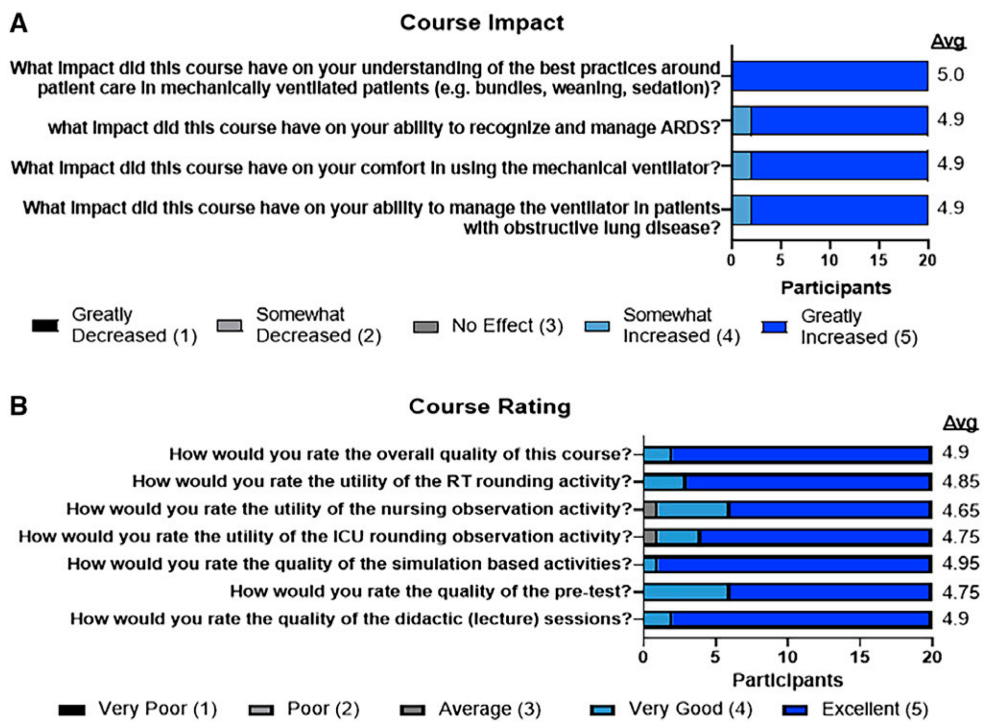


**Figure 3.** Participant assessment of course elements and impact. Oregon Health and Science University cohort participants were asked to rate the quality and impact of this course using a five-point Likert scale. (*A*) Course impact on participant knowledge and comfort in managing ICU patients requiring mechanical ventilation. (*B*) Assessment of overall quality and quality of different aspects of the weeklong course. Average Likert rating is shown to the right of graph. ARDS = acute respiratory distress syndrome; ICU = intensive care unit; RT = respiratory therapist.

improvements were seen in the areas of physiology and advanced/disease-specific concepts.

Similar to the OHSU cohort, the BDMS/Thailand cohort showed statistically significant improvements in all 10 core concepts, with the greatest improvements seen in ventilator emergencies/troubleshooting (40.9 ± 22.9% vs. 68.3 ± 22.4%), ventilation in obstructive lung disease (31.1 ± 25.5% vs. 53.0 ± 32.7%), waveform interpretation (31.7 ± 25.6% vs. 55.6 ± 27.8%), mode basics (40.7 ± 33.8% vs. 72.4 ± 29.7%), mechanics and maneuvers (38.5 ± 17.9% vs. 69.9 ± 23.6%), and ARDS (29.3 ± 29.1% vs. 60.2 ± 31.8%) ($P < 0.001$ for all). As with the OHSU cohort, the areas with the greatest improvement were those with the lowest baseline knowledge, with the largest improvement seen in the recognition and management of ARDS, with a doubling in the posttest versus pretest score (*see* Table E2).

## DISCUSSION

In this study, we developed and assessed a novel interprofessional, train-the-trainer curriculum for simulation-enhanced education in the best practice management of mechanically ventilated ICU patients, which could allow scalability across a large international regional network. In the first cohort, Thai physicians and nurses representing leaders in clinical practice, education, and simulation at BDMS came to OHSU and underwent a five-day, immersive course led by physician, nurse, and respiratory therapy experts. This course combined focused didactics with

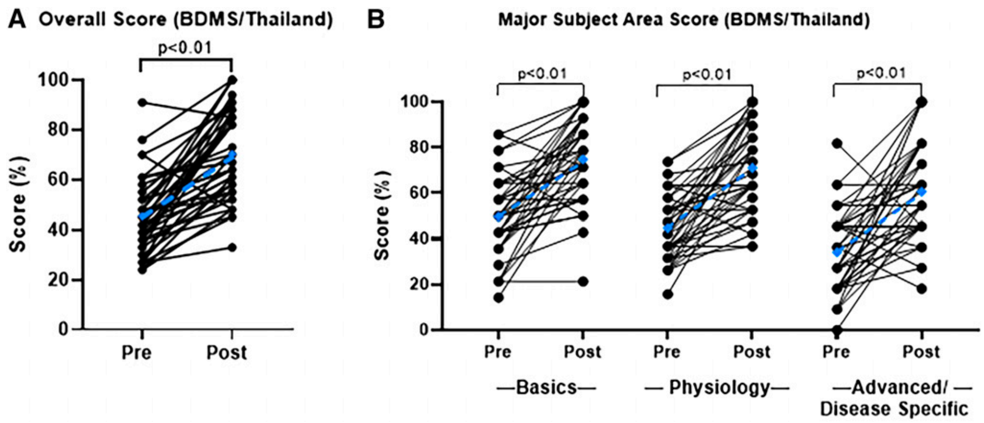


**Figure 4.** BDMS/Thailand cohort knowledge assessment: results from a 33-question knowledge assessment completed before and after participation in our course ($n = 41$ participants). (*A*) Overall scores of participants increased from a mean of 45.4 ± 15.0% to 70.3 ± 19.1% after completion of the course ($P < 0.01$). (*B*) The greatest improvements were seen in the major subject areas of respiratory physiology (from 44.8 ± 19.2% to 71.0 ± 19.2%) and advanced/disease specific (from 34.2 ± 17.6% to 60.5 ± 21.3%), followed by basics (from 49.7 ± 17.6% to 74.7 ± 18.4%) ($P < 0.01$). Pre- and posttest scores were compared using a paired *t* test. Blue dashed line denotes mean. BDMS = Bangkok Dusit Medical Services.

high-fidelity simulation and *in situ* clinical experiences, as well as training in how we developed and administered the curriculum. On completion of the course, participants demonstrated significant knowledge improvements in all core concepts, particularly in evidence-supported best practices in the prevention of ventilator-associated harm, the recognition and management of ARDS, and liberation from MV. These leaders then returned to their home hospitals in Thailand and implemented a lower fidelity version of the training for a larger multidisciplinary group of ICU and emergency nurses, combining didactics, demonstration, and low-fidelity simulation, demonstrating a significant improvement in core concept knowledge.

Although high-fidelity simulation is an excellent way to teach and train to clinical excellence, its limited availability and high cost make it not feasible to roll out on a large scale, particularly internationally. One of the most valuable parts of simulation is the ability to use the actual equipment (in this case, ventilators) and personnel available in a given hospital system, using deliberate practice and structured debriefs to train to best practices in a near-authentic setting. Using a train-the-trainer model allowed us to maximize the impact of this valuable, but limited, resource. Also core to our curriculum was training these clinical and educational leaders from Thailand not only in best practices but also in how we teach these best practices using didactics, simulation, and *in situ* experiences. Participants saw how we taught, how we paired brief didactic sessions with either simulation or bedside experiences to reinforce concepts, how we developed a curriculum that iteratively builds from basic concepts and skills to more complex ones, and how we used deliberate structured debriefs throughout. In addition, these leaders had the opportunity to lead debriefs and teach-backs for others within their cohort and received feedback from OHSU course leaders as part of their training. Then, together these leaders determined how to best deliver the curriculum in their home hospital system to allow further dissemination of knowledge and best practices in their own institutions, resources, and work flows, piloting the education at 2 of their 49 hospitals, with plans to expand across BDMS in the future.

Our course was designed to focus on why best practices need to be adopted (focused didactics), how best practices may be implemented in real-life situations (*in situ* experiences), and allowing deliberate practice of these skills in a safe environment, through high-fidelity simulation. Implementation of an interprofessional train-the-trainer MV curriculum was successful in increasing knowledge of best practices in the care of ventilated ICU patients not only in those who completed our OHSU-based high-fidelity simulation course but also across cultural boundaries when adapted and implemented across two hospitals in the BDMS system in Thailand.

### Strengths and Limitations

A strength of our study is the inclusion of an interprofessional team in performing the needs assessment and developing the training, both at OHSU and in Thailand. In one key aspect, ongoing physician, nurse, RT, and simulation expert collaboration between OHSU and BDMS allowed us to identify not only practice gaps but also differences in professional roles between countries, notably the absence of RTs in Thailand, whose roles are largely assumed by ICU nurses. Our curriculum was thus adapted to fit this practice model, which differs from the U.S. standard. Interestingly, the areas with the lowest pretest knowledge were similar between the cohorts and included more advanced MV topics, such as waveform analysis, performing and interpreting maneuvers to learn about respiratory mechanics, the recognition and management of ARDS and obstructive lung physiology, and responding to ventilator emergencies. These areas were identified in the Thai-site needs assessment and were not unexpected given that nurses, who constituted a majority of both cohorts, receive significantly less formal training in direct management of MV compared with physicians and RTs. Notably, the largest gains in knowledge from our curriculum were seen in these same areas, demonstrating the effectiveness of the curriculum. Despite the absence of RTs in Thailand, it was key to include RTs as well as nursing and physician leaders in the daily instruction at our site, both at the bedside and in simulation, and this aspect of the course was very highly valued by OHSU cohort participants on their course evaluations. Similarly, all OHSU simulations and bedside experiences were interprofessional, with physician and nurse participants working together, mirroring their complementary and collaborative authentic roles. Another significant lesson was the importance of having cross-cultural champions, not only in having our pre- and posttest knowledge assessments translated into Thai but also in having real-time translators at all live sessions to ensure that no lessons were lost in the training or debriefing.

Although the lead educators for the Thai-site cohort were themselves interprofessional, with a physician (N.P.) and a nurse (N.C.) coleading, one limitation of our study is that the early participants were all nurses, representing the ICU and emergency department. We hope to incorporate interprofessional training, with physicians and nurses and eventually physical therapists, in future sessions once the COVID-19 pandemic allows. In addition, we acknowledge that although we used the ABCDEF bundle as a framework for teaching best practices around the management of critically ill mechanically ventilated patients, our simulation training and knowledge assessment focused primarily on conceptual and hands-on ventilator management and included training in and assessment of spontaneous breathing trials. Additional work will need to be done to assess the impact of this course on knowledge acquisition for other components of the ABCDEF bundle. Another current limitation of our study is that we do not yet know the impact of our educational curriculum on real-world practices and patient outcomes. Improvement in knowledge of key best practice ventilator concepts is a vital step in improving patient outcomes but must be followed by practice improvement at the bedside. The ongoing collaboration between OHSU and BDMS is gathering data on key performance metrics, including adherence to lower tidal volumes, regular measurement of plateau pressures, and performance of daily spontaneous breathing trials as well as patient outcome metrics including ventilation-free days, delirium, and mortality. Using these and other data metrics, we hope to link our training to improved performance. Future plans include the resumption and expansion of the curriculum across more hospitals within the BDMS system and repeated knowledge testing of participants to look at the long-term retention of core concepts.

## Conclusions

An adaptable, interprofessional, train-the-trainer, simulation-enhanced MV curriculum was successful in increasing knowledge of best practices in the care of ventilated ICU patients. The two-part educational model, with a high-intensity, high-fidelity course in the United States to train physician and nurse experts in critical care, simulation, and education, followed by *in situ* education of nurses in Thailand, demonstrates the feasibility and effectiveness of a curriculum that can be tailored to the resources of an individual hospital system or even country and may be used as a model for improving education in best practice management for ICU patients across the world.

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