Impact of Simulation-based Mastery Learning on Management of Massive Hemoptysis

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ABSTRACT

Background: The management of massive hemoptysis is a high-risk, low-volume procedure that is associated with high mortality rates, and pulmonary and critical care medicine (PCCM) fellows often lack training. Simulation-based mastery learning (SBML) is an educational strategy that improves skill but has not been applied to massive hemoptysis management.

Objective: This pilot study aimed to develop a high-fidelity simulator, implement an SBML curriculum, and evaluate the impact on PCCM fellows managing massive hemoptysis.

Methods: We modified a simulator to bleed from segmental airways. Next, we developed an SBML curriculum and a validated 26-item checklist and set a minimum

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passing standard (MPS) to assess massive hemoptysis management. A cohort of traditionally trained providers was assessed using the checklist. First-year PCCM fellows reviewed a lecture before a pretest on the simulator using the skills checklist and underwent rapid-cycle deliberate practice with feedback. Subsequently, fellows were posttested on the simulator, with additional training as necessary until the MPS was met. We compared pretest and posttest performance and also compared SBML-trained fellows versus traditionally trained providers.

Results: The MPS on the checklist was set at 88%. All first-year PCCM fellows ($N = 5$) completed SBML training. Mean checklist scores for SBML participants improved from 67.7 ± 8.4% (standard deviation) at pretest to 84.6 ± 6.7% at the initial posttest and 92.3 ± 5.4% at the final (mastery) posttest. Traditionally trained participants had a mean test score of 60.6 ± 13.1%.

Conclusion: The creation and implementation of a massive hemoptysis simulator and SBML curriculum was feasible and may address gaps in massive hemoptysis management training.

The management of massive hemoptysis is challenging and continues to carry a high risk of mortality despite advances in fiberoptic technology, diagnostic imaging, and interventional radiology (1). Massive hemoptysis management is a high-risk, low-volume procedure that is not formally taught in almost half of all pulmonary and critical care medicine (PCCM) fellowship programs (2). Existing cognitive aids to manage massive hemoptysis have the potential for offloading mental energy in this high-leverage scenario, but real-world experience remains a crucial yet inconsistent experience for learners (3, 4).

Simulation-based education (SBE) is effective for teaching difficult psychomotor tasks such as emergent airway management and complex situations such as advanced cardiac life support (5, 6). However, SBE does not necessarily hold learners to high, uniform standards or assess for clinical competence. Simulation-based mastery learning (SBML) is a rigorous, competency-based educational model with foundations rooted in constructivist, behavioral, and social learning theories (7). In contrast to traditional SBE, SBML reduces or eliminates variability in trainee skill after an educational intervention by requiring each learner to meet or exceed a predetermined minimum passing standard (MPS) on a simulated skills assessment (6, 8–13). The MPS defines the minimum skill level required to assure safe patient care. To achieve this goal, SBML requires that all trainees participate in a simulated pretest assessment, followed by educational sessions that use deliberate practice. Learners are ultimately retested via a simulated posttest until they are able to meet or exceed the MPS. No SBML curricula currently exist for the management of massive hemoptysis. Further, prior SBE programs for massive hemoptysis management have not focused on the role of bronchoscopy, possibly because there are no commercially available manikins capable of simulating segmental airway bleeding (14, 15).

The present pilot study has the following three aims: first, to design a segmental airway bleeding simulator to simulate massive hemoptysis in a realistic clinical environment; second, to design and

implement a bronchoscopic management of massive hemoptysis SBML curriculum for PCCM fellows; and third, to evaluate if the curriculum improves skills in the simulated environment.

METHODS

Study Design and Setting

We performed a pretest–posttest pilot study of the management of a simulated case of massive hemoptysis among first-year PCCM fellows, along with a traditionally trained comparison group, at a tertiary-care academic medical center in Chicago, IL, in January and February 2023. The Northwestern University Institutional Review Board approved this study.

The simulation was conducted *in situ* within the bronchoscopy suite and was facilitated by an interprofessional care team that included one interventional pulmonary (IP) faculty member (E.S.M.), two senior PCCM fellows (T.J.R. and K.M.V.), two registered nurses from the bronchoscopy suite, and a respiratory therapist.

Participants

All first-year PCCM fellows ($N = 5$) during the study period were eligible to participate in the study. Exposure to the SBML educational intervention was provided as a part of the fellows' core didactics regardless of participation in the study. All participants provided written informed consent before participation. The fellowship program director (C.J.S.) was not involved in study recruitment and was blinded to enrollment status until all potential participants had consented to participate. A "traditionally trained" group ($N = 4$; two PCCM attending physicians, one thoracic surgery advanced practice provider [APP], and one critical care medicine fellow) served as the comparison group. This group had varying levels of exposure to formal and informal training in the management of massive hemoptysis, including lecture, simulation, and experiential learning, but did not receive SBML.

Technical Description and Simulator Development

To create our massive hemoptysis simulator (Figure 1), we modified the commercially available AirSim X bronchoscopy simulator (TruCorp). The resulting simulator is portable, maintains high fidelity of upper and lower airway anatomy, selectively bleeds from the desired segmental airway, blinds the trainee to the source of bleeding unless identified bronchoscopically, and allows for real-time adjustment of the flow rate using standard intravenous pump equipment available in most clinical settings. The total cost of materials, including the AirSim X simulator, was approximately $3,800. The equipment used to modify the commercially available simulator cost <$100 (*see* data supplement for a full description of simulator creation).

The simulated case scenario was performed with Olympus BF-P190 and BF-1TH190 bronchoscopes (Olympus America), 6- and 7-F Fogarty balloons (Edwards Lifesciences), and 7- and 9-F Arndt endobronchial blocker sets (Cook Medical).

Instrument Design

We developed a 26-item "Bronchoscopy for Management of Airway Bleeding" checklist (*see* data supplement) using relevant literature, best practices, and checklist design strategies described by Stufflebeam (16). We applied published frameworks to enhance the validity of our checklist, focusing on hypothesis-driven inquiry, content refinement, and collection of diverse viewpoints (17, 18). Content

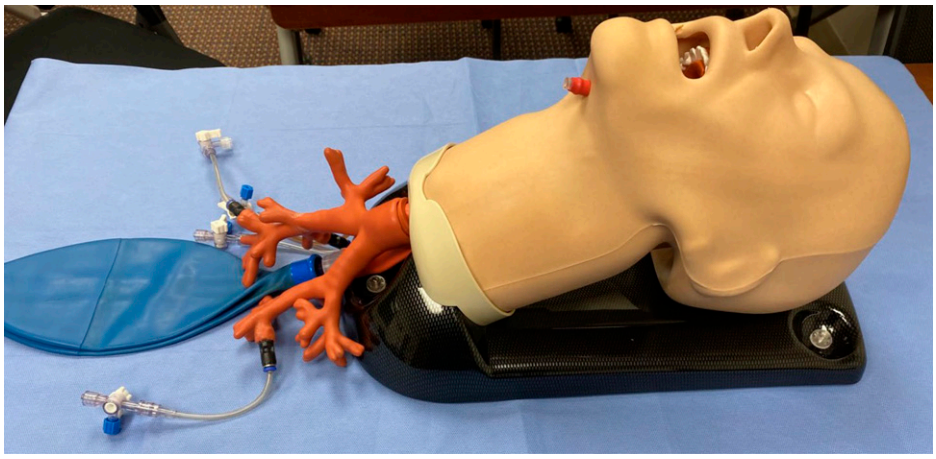

Figure 1. Massive hemoptysis simulator consisting of an AirSim Advance Bronchi X (TruCorp) modified to allow for selective bleeding from the right upper lobe, right lower lobe, or left lower lobe. *See* data supplement for a full description of simulator design.

from the checklist centered on psychomotor, cognitive, and communication skills domains. The checklist divided the simulated scenario into preparatory, procedural, and postprocedural management steps. After the initial checklist was developed, we employed a modified Delphi technique with six board-certified IP faculty physicians from different institutions and four SBML content experts (two medical doctors, one Ph.D. professor, and one clinical research registered nurse) to finalize the checklist content. The scenario was tested on the traditionally trained comparison group, whose performance was assessed using the checklist, and the checklist wording was modified for clarity. Scoring for the traditionally trained group was used to assess interrater reliability (IRR) using the κ-coefficient for the skills checklist. The IRR between evaluators (K.M.V. and T.J.R.) was high ($\kappa = 0.921$).

Subsequently, a different panel of 10 physicians from 6 different hospitals (two PCCM attending physicians, one thoracic surgery attending physician, five IP attending physicians, and one IP fellow) performed a virtual standard setting using the Mastery Angoff method to set the MPS (19). In brief, this method asks experts to review each checklist item individually and estimate the percentage of well-prepared trainees who would perform the item correctly at posttest. The mean value generated by querying each item is used to determine the MPS. Well-prepared trainees are those who can perform the skill or procedure safely and independently. In our standard setting, we chose not to include any compulsory items whose omission would result in automatic failure to reach the MPS (20). Each essential step was linked in such a way that omission would virtually obligate a failure to reach the MPS.

Intervention

Within 1 week of SBML training, members of the intervention group each verbally attested to having asynchronously viewed an evidence-based, didactic online video review created by four study authors (E.S.M., A.C.A., T.J.R., and K.M.V.). This review covered epidemiology, appropriate imaging evaluation, bronchoscopic interventions, and a stepwise approach to the management of massive hemoptysis from segmental airway bleeding. Next, the participants underwent

a baseline skills assessment (i.e., pretest) using the 26-item skills checklist.

The simulated case scenario (*see* data supplement) prompts the learner to respond to hemoptysis that develops after a transbronchial biopsy. The learner is expected to manage the simulated patient through decompensation, endotracheal intubation, and placement of a bronchial blocker and to provide handoff to the oncoming intensive care team. After completion of the pretest, learners participated in 90 minutes of rapid-cycle deliberate practice in the same *in situ* simulation environment in groups of two or three in which they cycled through the simulation with structured breaks for specific feedback, reflection, and repetition of key skills. Instructors (E.S.M., T.J.R., and K.M.V.) identified key decision points for rapid-cycle deliberate practice *a priori* from the skills checklist; feedback was tailored to observations based on global learner performance throughout the testing sessions. Learners were not directed to specific test items, and the checklist was never shared with the learners.

Four weeks later, all participants completed a posttest assessment to evaluate whether they were able to meet or exceed the MPS. The simulated posttest case scenario was modified from the pretest, and the bleeding segment varied with each encounter. Those who were unable to meet or exceed the MPS at the initial posttest underwent an additional 60-minute cycle of deliberate skills practice on the simulator, followed by retesting within 2 weeks of the initial posttest attempt, until the MPS was achieved.

Measurement

Learner characteristics including age, gender, number of logged bronchoscopies, and self-reported patient experience with airway bleeding management were collected by self-reported questionnaire and procedure log information. Learners also reported pre- and postintervention confidence in their ability to perform bronchoscopy and manage massive hemoptysis, as well as their perceptions of simulation-based curricula. Survey data were collected and stored using Qualtrics XM software (Qualtrics). The checklist scoring, performed by a primary rater (T.J.R.), was dichotomous and graded as 1 (done correctly) or 0 (not done or done incorrectly). If learners required prompting at any point during the scenario, they would not receive credit for completing the corresponding checklist item.

Statistical Analysis

We used descriptive statistics to report participant demographic data, clinical experience, and learner performance and self-confidence. Given the small sample of learners, tests of statistical significance were not applied to the results of this pilot intervention. We reported percent agreement for IRR for the SBML group because there was not enough variation to calculate a κ-statistic. Statistical analysis was performed using GraphPad Prism (version 9.0; GraphPad Software).

RESULTS

All five eligible learners consented to participate in the study and completed SBML training. Learner characteristics and experience are detailed in Table 1. Baseline experience with bronchoscopy before participating in the study was variable, but all participants had logged at least 25 bronchoscopy procedures at the time of enrollment. The traditionally trained providers described above served as a comparison group.

The MPS was set at 23 of 26 correct (88%) on the skills checklist. None of the

Table 1. Learner characteristics of simulation-based mastery learning trainees ($N = 5$)

Characteristic	Value
No. of bronchoscopies logged, mean ± SD	38.4 ± 8.88
Prior massive hemoptysis training, *n* (%)	
No	5 (100%)
Yes	0
Prior clinical experience with massive hemoptysis, *n* (%)*	
No	2 (40%)
Yes	3 (60%)

*At the time of initial assessment.

SBML trainees met the MPS (mean, 67.7 ± 8.42% [standard deviation]) on the pretest. After completion of the SBML training, posttest scores improved (mean, 92.3 ± 5.43%). Three participants met or exceeded the MPS on the initial posttest, and two required an additional cycle of deliberate practice, exceeding the MPS on the first additional posttest. Additionally, SBML-trained participants outperformed the traditionally trained comparison group before and after the SBML intervention (Figure 2). The percent agreement between raters for the SBML group was 100%.

The most consistently missed or incorrectly performed checklist items among SBML trainees before the intervention included switching to a smaller bronchoscope, loading and securing the bronchial blocker, and verbalizing a reinspection plan. Improvement in performance for each of these items was observed at the time of the first posttest attempt.

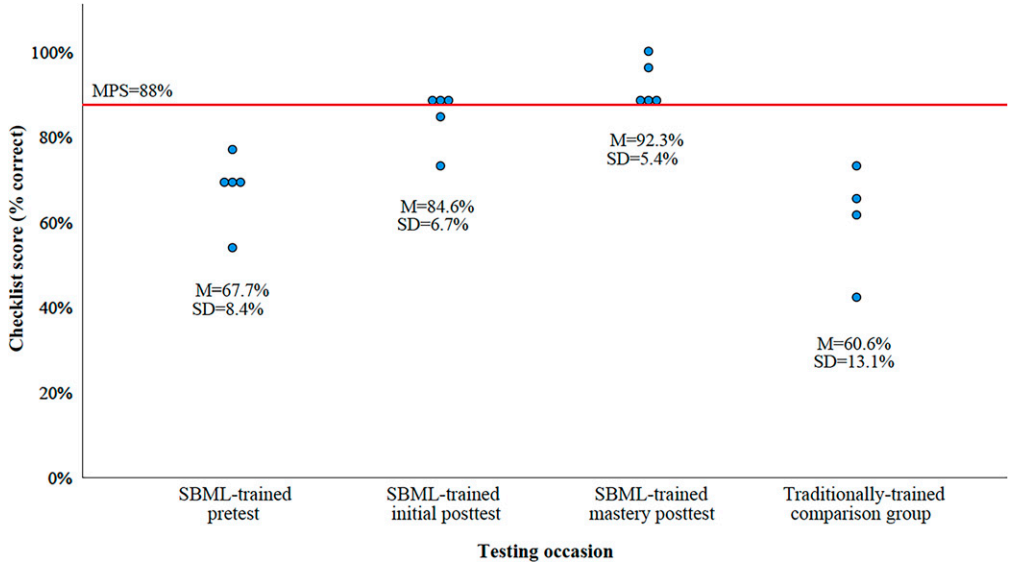

Figure 2. Pretest and posttest scores (percentage correct) on a 26-item massive hemoptysis management checklist among SBML–trained fellows and traditionally trained providers. Each circle represents an individual participant. M = mean; MPS = minimum passing standard; SBML = simulation-based mastery learning; SD = standard deviation.

Participants' confidence in managing massive hemoptysis showed improvement in all domains (*see* data supplement). All strongly agreed that participation in the simulation experience would improve their performance in managing a real case of massive hemoptysis and that repetitive practice with simulation increased the educational merit of the experience, as did its interprofessional nature.

DISCUSSION

Airway bleeding is a known complication of bronchoscopy, yet strikingly few PCCM trainees undergo formal training or competency assessment (2). Experiential learning can be difficult to guarantee because of its unpredictability and relative rarity of occurrence. Our pilot study addresses this gap by designing an airway bleeding simulator and implementing and assessing an SBML curriculum.

Our first aim was to develop a simulator capable of reproducing airway bleeding because none are commercially available and cadaver training is resource-intensive. By modifying a widely available manikin with equipment readily procured in the clinical environment, we created a realistic and reproducible simulator. Our simulator may be modified to bleed from any segmental bronchus, ensuring variability with retesting. Its portability allows for the simulation to be run in the bronchoscopy suite, the intensive care unit, or even at other institutions.

Next, we designed and implemented an SBML curriculum for bronchoscopic management of massive hemoptysis. Our pilot results demonstrate successful implementation of the curriculum, which was positively received by fellows. As in the case of other complex procedures, successful management of massive hemoptysis entails a high degree of cognitive load alongside the application of a technical skill (21). We conducted the simulation in our hospital bronchoscopy suite and involved the full interprofessional bronchoscopy team to foster a shared cognitive approach, mimicking real-world emergencies (22). This is the first high-fidelity SBML curriculum for massive hemoptysis. Others have previously demonstrated the value of SBML for PCCM-relevant skills across several domains, including cognitive procedures like advanced cardiac life support, advanced communication in breaking bad news and discussing code status, and procedures including central venous catheter insertion, thoracentesis, and lumbar puncture (6, 8, 10, 11, 13, 23). Our work adds to the growing body of literature that suggests that SBML may also be effective for skills transfer in high-risk, low-volume procedures (24).

Our final aim was to evaluate whether our SBML curriculum would improve skills in massive hemoptysis management in the simulated environment. No validated checklist specific to the management of massive hemoptysis existed, so our instrument was created to fill this gap. Our MPS was set with input from diverse disciplines (interventional pulmonology, thoracic surgery), professions (medical doctors, APPs, registered nurses), and practice settings (academic and community), improving its validity and generalizability. After participating in the curriculum, participants unanimously agreed that the simulated scenario would improve their ability to manage real airway bleeding emergencies, without evidence of evaluation apprehension (25). Although self-confidence does not always map to procedural competence (26), the participants' objective skills in managing the scenario also improved following completion of the SBML curriculum, with all five learners

ultimately achieving the MPS. Despite self-reported clinical experience in managing massive hemoptysis in three of our five learners, none of them met the MPS at the pretest. This suggests that clinical exposure alone may be insufficient to guarantee competence. An unexpected observation was that the SBML trainees achieved higher baseline scores before the intervention than the traditionally trained comparison group. This suggests that independently practicing providers may benefit from dedicated training for massive hemoptysis management. Furthermore, SBML trainees' higher performance may reflect the impact of the asynchronous lecture, which only the SBML group viewed before the baseline assessment. Despite this exposure, none of the SBML participants met the MPS on the pretest, supporting the notion that lecture-based training may be insufficient for teaching complex psychomotor skills such as massive hemoptysis management.

This study has several important limitations. First, it was conducted at a single institution, and, for the sake of feasibility, we limited our intervention to first-year PCCM fellows. Therefore, we cannot extrapolate our findings to other settings and training contexts and are unable to perform tests of statistical significance. However, our technical innovation and simulation are intentionally designed to be portable, scalable, and adaptable to clinical context. Furthermore, SBML curricula such as this have been successfully disseminated in the past (27, 28). Second, feedback for deliberate practice was based on performance on the pretest checklist, which may indicate that the SBML-trained group was merely "trained to the test." However, we designed the checklist to reflect expert consensus on the information and skills required to successfully manage an episode of massive hemoptysis, and the SBML trainees did not have access to the skills checklist during training. In mastery learning, the crucial baseline assessment allows "test-enhanced learning" to give learners directed performance feedback that results in effortful, durable learning (29). Third, this brief report lacks data on the long-term retention of skills and knowledge. Finally, our study did not address patient-level outcomes, an important target for further exploration. Future work is also planned to elucidate the optimal time interval for reinforcement by retesting our learner group at 12 months. We also intend to expand the clinical context outside of the bronchoscopy suite, extend the educational opportunity to other learner groups such as attending physicians and APPs, and assess the impact of training on other members of the interprofessional bronchoscopy team.

Conclusions

We created a massive hemoptysis simulator and implemented an SBML curriculum, including a skills checklist using validated methodology, among PCCM trainees. The education was favorably received and is one strategy to address gaps in massive hemoptysis training.

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