Mannequin-Based Simulation to Reinforce Pharmacology Concepts

Michael Seropian, MD, FRCP(C);
Dawn Dillman, MD;
Kathie Lasater, EdD, RN;
Jesika Gavilanes, MA

Simulation education provides many new learning opportunities to healthcare training. This article delineates a method that utilizes a variety of teaching methods that include structured lecture-based education, active simulation-based education, and reflective inquiry. A course in pharmacology is used as an example to show how these different methods can be employed to offer students an immersive experience that reinforces traditional lecture-based learning. The paper is presented in such a way that it is easily applied to multiple situations and includes schematics, evaluation data, and equipment lists. Evaluation data strongly supported the continued use of this methodology.
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Mannequin-based simulation is an established healthcare training technique that has been used in medical schools, graduate medical education (GME), and nursing schools.[1,2] Although this technology has been available for almost 2 decades, its integration into medical school curricula is not mainstream. In this article, we describe the methodology and theoretical basis for teaching clinically relevant pharmacology, using lecture-based learning with mannequin-based simulation.

In this course, we used simulation in an auditorium to enhance the lecture and demonstrate clinical relevance. The students learn not only what the drugs do (in this case, neuromuscular blockers), but also the direct and indirect multisystem consequences of drugs that may primarily act within only 1 system. Such contextual learning helps to instill important professional concepts and develop clinical judgment in a low-risk, safe environment.[3,4]

Teaching Methodology

Target Population

First-year medical students, although any student taking a pharmacology course would also be suitable (nursing, allied health, etc.). Our population includes approximately 100 medical students who are 5 months into their first year. Other student populations taking a pharmacology course would also be suitable (nursing, allied health, etc.). We have used this teaching method annually for the last 4 years as an adjunct to the neuromuscular blocker lecture in the pharmacology course.

Student Prework

The target drug class is neuromuscular blocking (NMB) agents. In a standard lecture 2 to 3 days before the simulation session, the students learn about the pharmacodynamics and pharmacokinetics of NMB agents and how NMB agents bind to the receptors at neuromuscular blocker junctions. They also learn about reversing these agents. Students receive handouts and references to established core textbooks. Students should have knowledge about sedatives and hypnotics.

Objectives

Upon completion of this learning activity, the student will be able to:

1. Describe the primary site and system of action of neuromuscular blocking agents.
2. Verbalize clearly the different systems that are impacted after the administration of an NMB, including musculoskeletal, respiratory, cardiovascular, and central nervous systems.
3. Identify the equipment needed before and during administration of an NMB.
4. Participate in a discussion about the consequences of administering an NMB.
5. Describe clearly how an NMB affects the Airway, Breathing, and Circulation (ABCs).
6. Appreciate the difference between paralysis and anesthesia and offer other medications that would mitigate awareness and avoid the cognitive sense of being locked in.
7. Describe how an NMB will impact oxygen saturation.
8. Distinguish between oxygenation and ventilation.
9. Identify the drugs used to reverse NMB agents, including their effects at both muscarinic and nicotinic sites.
10. Discuss how drugs such as atropine and glycopyrolate mitigate the unwanted or potentially harmful effects of reversal agents.

Brief Class Description

Two to 3 days after the NMB lecture, the first year class is divided into 2 groups, and each group participates in a 1-hour session using a high-fidelity computerized mannequin in an auditorium setting. Four student volunteers provide care for the mannequin while the other class members remain seated and simultaneously observe the activity occurring at the mannequin bedside as well as a live video feed of the mannequin's vitals signs (including blood pressure, pulse

From the Department of Anesthesiology and Peri-Operative Medicine (M.S., D.D., K.L.), Faculty Schools of Medicine and Nursing (M.S., K.L.), and OHSU Simulation and Clinical Learning Center, Oregon Health and Science University (J.G.), Portland, Oregon.

Reprints: Michael Seropian, MD, FRCPC, 3181 Sam Jackson Park Road, Portland, OR 97239. (e-mail: seropian@ohsu.edu).

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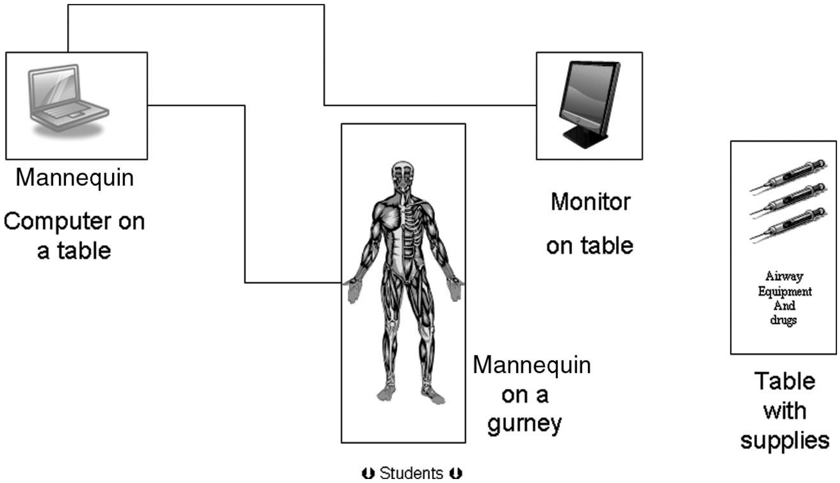


Figure 1. Equipment layout.

oximetry, and electrocardiogram). The session emphasizes the steps for administering an NMB and managing the clinical sequelae of each action taken. The instructor pauses the simulation at each critical point to allow students to assess the current situation and discuss what happened, identify the consequences, and determine what actions must be taken to keep this patient safe physically and emotionally.

Faculty and Staffing Requirements

Teachers must be knowledgeable in mannequin-based simulation. It is best to have 2 instructors: one to run the computer/simulator patient voice and the other to help the students manage the patient (mannequin). Alternative arrangements can include a single instructor and another individual familiar with mannequin operations and setup.

Setup and Equipment Requirements

The simulator is set up and managed to create high psychologic fidelity[5] for participants and observers. Setup and smooth operation of the mannequin and audio-visual (AV) system are paramount (*see "Lessons Learned" for additional tips*). All wires and cables must be secured, and any cables on the floor must be covered to avoid tripping hazards to staff and students, not to mention potential damage to the equipment.

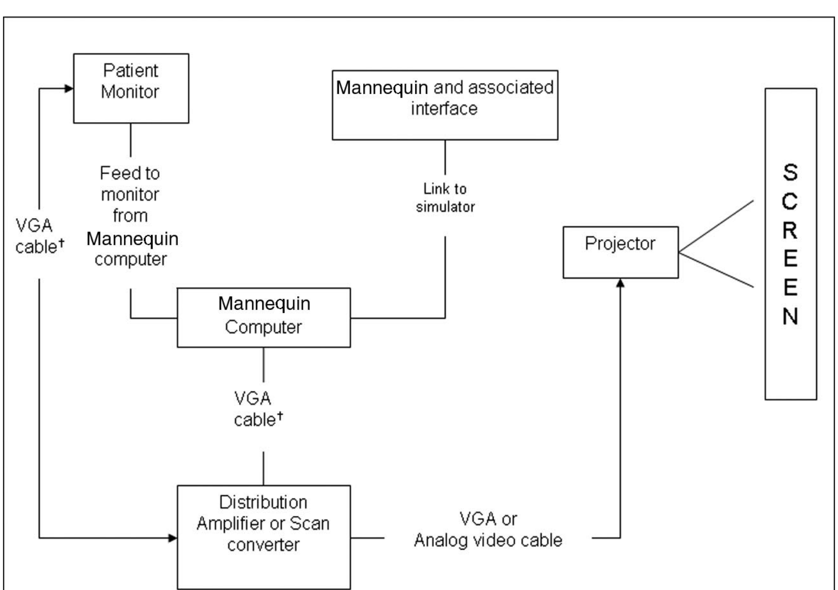
Figures 1 and 2 illustrate a general setup that can be used with computerized mannequins from a variety of manufacturers. Because we used the Laerdal product, the monitor layout and equipment list use SimMan as an *example* to provide a sense of the detail required. The suggested equipment is described in Appendix 1.

Monitor setup should include ECG, O_2 saturation tracing, and noninvasive blood pressure (NIBP). The train-of-four reading (a method commonly used to measure the degree of NM blockade) is located in the lower right corner with respiratory rate directly above it. The NIBP should be set to auto mode, cycling every 2 to 3 minutes.

Figure 2 describes a video setup that allows the students to visualize the mannequin's vital signs in real time on the auditorium screen via an LCD projector.

Detailed Class Description

The mannequin is placed at the front of the auditorium on a stretcher, and a variety of drugs and ventilation equipment



† VGA cable source and routing will vary depending on mannequin manufacturer. Several different layouts are represented here.

Figure 2. Audio-visual setup diagram (example).

is available on a table adjacent to the "patient." Students in the audience are seated so that they can see the mannequin as well as the vital signs projected onto the auditorium screen.

After an introduction to the purpose and objectives of the class, 4 students volunteer to take care of the patient over the next hour and receive an orientation to the mannequin, including a brief medical history of why his condition might require an NMB agent. With help from an instructor at a remote location, the mannequin speaks to the students. Another instructor remains at the bedside at all times to assist the volunteers.

The students then select an NMB agent, and the instructor assists with the IV injection, if necessary. Approximately 1 to 2 minutes later, the patient starts to complain of trouble breathing, and the heart rate and blood pressure simultaneously increase. The patient becomes apneic, with saturations dipping into the mid-60s. As the situation becomes urgent, the instructor pauses the simulation and engages the students in a discussion about what has happened and what are possible next steps, including the role of mask ventilation and intubation. On the basis of the earlier lecture and their readings, the students review the pharmacology of NMB agents and their physiologic impact on the respiratory system and the patient's response. The discussion focuses on the airway consequences and the ability to breathe, with special attention given to the difference between oxygenation and ventilation.

The students then consider the difference between anesthesia and pharmacological paralysis. They quickly recognize the distress of being intubated while "locked in," ie, completely awake but unable to communicate or move. The environment is supportive, and the students are reassured that this process will help them to anticipate and preempt these issues in practice. Based on this awareness of the patient's dilemma, the discussion shifts to drugs such as benzodiazepines, hypnotics, and narcotics that can be administered as a sedative before paralysis to provide comfort and minimize recall. One of the 4 volunteers then gives a suggested drug, and the patient's heart rate and blood pressure return to a more normal range.

When it is time to return the patient to his normal awake state, his breathing is spontaneous but weak, and he shows a train-of-four (TOF) of ¾ with fade (¾ = 3 twitches out of 4; fade = a sequential decrease in amplitude of the 3 twitches). The students suggest possible actions, including drugs. If the volunteers elect to remove the endotracheal tube, the patient begins to desaturate, requiring bag-mask ventilation again. Once again, the students and instructor discuss what is happening at the NM junctions in the setting of a TOF ratio of 3/4. Recognizing that the patient has residual NM blockade, the students suggest that the patient requires an anticholinesterase agent, such as neostigmine, and a volunteer administers the drug. When his heart rate and blood pressure drop precipitously, further discussion prompts the students to recall that neostigmine acts at the muscarinic receptors of the heart causing bradycardia; and they suggest drugs such as atropine or glycopyrolate to counteract this un-apposed effect. After the drug is administered, the heart rate and blood pressure stabilize to normal parameters. The patient's breaths become deeper, and his respiratory rate decreases. Assuming the endotracheal tube has been removed, the patient starts to talk; and the reversal is complete.

The instructors review the session, emphasizing how a drug with a specific site of action can affect many different systems. They stress the consequences and the sequence of drug administration as well as the equipment required to ensure patient safety. A customized course evaluation is distributed at the conclusion of the course.

Evaluation

Method

The study of the student evaluation data was approved by our Institutional Review Board at Oregon Health & Science University. From February 2004 through 2006, 3 separate first-year medical student classes were exposed to this teaching methodology/format. Each class had a total of 100 students. After the class, each student was asked to complete an evaluation form. The evaluation included 10 questions, using a Likert scale from 1 to 5 (1 = strongly disagree and 5 = strongly agree). The evaluations were collected, compiled, and analyzed. Any written comments were reviewed individually and grouped according to their primary nature/content. Appropriate statistical analysis was applied; P values <0.05 were considered significant.

Results

A total of 269 students attended the class over the 3 years. The attendance and evaluations completed for 2004, 2005, and 2006 were 86, 94, and 89, respectively. The data for the evaluations is presented in Table 1. Students rated the course consistently high.

The data suggests that students perceived that the course provided them with better clinical understanding and complemented their lecture on NMBs. Based on scores to questions specifically about the format, the results also showed a strong preference for this format. Table 2 provides a breakdown of comments according to their content. The comments were very positive and focused mainly on how they liked the session and would like more such learning opportunities. A brief sampling of significant comments is provided in Appendix 2.

DISCUSSION

Educators are often confronted with a theory-practice gap that is not easily addressed with lecture alone.[4] Lecture-based teaching is an efficient learning tool in medical education, but it is not as effective as experiential learning.[6,7] By engaging our student volunteers directly in administering medications and the audience in guided discussion,[8] the exercise becomes more learner-centered[9] and memorable.[10,11]

Not only do people learn differently,[7] but they are also more likely to retain information that is taught by using multiple senses and methods. For example in one study, recall was 10% 3 days after only hearing new information, 20% 3 days after only seeing new information, and 65% 3 days after both hearing and seeing.[12] Simulation offers students an opportunity to engage multiple senses in complex and realistic patient care situations, fulfilling the need of adult learners for "relevant and accurate learning situations."[13] In addition, the

Table 1. Neuromuscular Course Evaluations for 2004–2006

Assessment Variables	2004 n = 86 Mean* (SD†)	2005 n = 94 Mean (SD)	2006 n = 89 Mean (SD)
Session was helpful	3.9 (0.85)	4.5 (0.65)	4.6 (0.58)
I better understand the clinical implications of neuromuscular agents	4.0 (0.90)	4.4 (0.66)	4.5 (0.57)
Patient simulation was a useful tool	4.1 (0.95)	4.6 (0.66)	4.7 (0.49)
The teacher(s) was/were helpful	4.1 (0.82)	4.7 (0.51)	4.6 (0.55)
The material was presented accurately	4.3 (0.78)	4.8 (0.48)	4.6 (0.51)
The audio-visual aides helped my learning	4.1 (0.96)	4.7 (0.61)	4.5 (0.66)
I prefer traditional lecture teaching methods	2.2 (1.08)	1.94 (0.88)	2.0 (0.84)
I would like more simulation education in my training	4.3 (0.77)	4.6 (0.58)	4.6 (0.63)
This session was complementary to my class on neuromuscular blockade	4.4 (0.82)	4.6 (0.53)	4.7 (0.66)
I found this format engaging	**	4.7 (0.56)	4.6 (0.70)
Mean Scores Combined	3.9 (0.62)	4.3 (0.39)	4.4 (0.37)

*Scale used included: 1 = Strongly disagree to 5 = Strongly agree.

No statistical differences noted between years.

†SD = Standard Deviation.

**This question not asked in 2004.

Table 2. Student Comments (Grouped)

Class of Comments	Students Who Wrote Comments (n = 69)
Thought format was relevant to their current & future training	29
General or specific comment about liking the course	22
More information before class or do later in semester	15
Desire more simulation sessions in their curriculum	11
Would like smaller groups so everybody could do the hands-on	5
Technical problems, issues and commentary	5

realism is enhanced when students can see the consequences of their decisions and actions.[13]

The learning experience described in this article occurs very early in the medical curriculum, and students are likely to revisit these pharmacologic principles with real patients in a variety of settings. This is characteristic of a spiral curriculum and gives the learner reinforcement through different experiences.[14]

Some may conclude that our simulation scenario lacks realism and has no clinical relevance. However, students seem to suspend disbelief because the session provides a high level of psychologic fidelity.[3,5] Both the volunteers and those in the audience experience active learning using this method.[2] By using simulation with guided discussion, the students can learn to apply clinical concepts to real-life clinical issues. Students in past studies have indicated that simulation integrates their learning from lectures, readings, and clinical experiences.[3] Students are often motivated to return to their texts to better understand the concepts.

Data from the evaluations confirm much of the theory and benefits of this format, supporting its continued use and possible expansion. Comments were similar to those from smaller groups who use simulation at our institution and indicate efficacy in larger class sizes.

Our school is exploring a variety of simulation-based strategies based, in part, on the success of this course. For example, the director of the second-year basic science course on circulation used simulation to demonstrate antiarrhythmic pharmacology. A white-paper by faculty experienced in simulation education is guiding expanded integration of simulation into the school's curriculum (including evaluation).

Future Research

Future studies of simulation may include larger sample sizes, more classes, and a comparison study of downstream training outcomes in students who are exposed to this teaching format and those who are not. The evaluations, although good indicators of an individual's attitude and thoughts, do not reliably predict long-term outcome (positive or negative).

Lessons Learned

Simulation education relies on organizational skills that are quite different from lecture-based teaching. Prior testing of equipment, for example, cannot be overstressed. When this class was initially offered, problems with equipment sometimes caused a half-hour delay, and students were restless waiting for the class to begin. Skilled technical personnel combined with content experts in the clinical use of NMBs are also important. We continue to learn from our experience as well as the evaluations and share the following lessons learned:

- The traveling equipment, including mannequin, audio-visual equipment, and medical supplies, should be carefully inventoried and listed to ensure that all the relevant equipment is there when you need it. A laminated list is most useful. Pictures and schematics are also important.
- An expert should visit the class site at least a week before the session to ensure that all equipment is compatible and to preempt specific needs and unanticipated issues.
    - The AV system should be checked for functionality and compatibility. This is particularly important

since the AV hook-up can change from one year to another.
  - Ensure that adequate live power outlets are accessible to the equipment.
  - More time may be needed in environments that are less familiar or that are poorly equipped for this type of activity.
- Set up the mannequin the night before, if possible, or at least 1 hour before class time to allow for troubleshooting. Because of the limited time structure of this course, resolving technical issues immediately before or during class time can be problematic.
  - Carry troubleshooting equipment and a variety of adapters. This rule becomes less relevant when frequently using a specific location.
  - Bring extra mannequin parts, especially those that are prone to failure (varies by manufacturer).
  - Bring a tool kit! If a repair is needed, it is not likely that the classroom support personnel will have tools.
- Audio has been our largest challenge. The number of technically related comments was small overall but still bears noting. If the monitor beeper or the alarms are too loud, they may drown out the instructor or the students. Post a team member at the back of the auditorium to check the audio and adjust the volumes as needed. It is important to do this when the students are present as the acoustics are very different in an empty room. Because the instructors cannot remain behind a podium, they should use lavalieres if the acoustics of the room require it.

We have learned from the evaluations that some students love precourse handouts. Out of a concern for inhibiting interactive and spontaneous exchange, we were reluctant to provide these in the past. This past year, however, we developed 2 handouts: (a) one that provides a brief outline of the concepts to be covered (distributed before the session), and (b) a comprehensive review of the material covered in the session (distributed at the end of the class).

CONCLUSION

In a pharmacology course for first-year medical students, the authors used an interactive learning strategy to link the theory of neuromuscular blocking agents and related drugs to their effects on a simulated patient. Four student volunteers, assigned to care for the "patient," and their colleagues, seated in the audience, interacted with 2 faculty members who guided the exercise and discussion and provided hands-on assistance to the volunteers.

This learning strategy helps new medical students think about the pharmacokinetics of drugs and the consequences of administering them. The broad array of multisystem impacts can be demonstrated safely and more effectively in this context that engages the senses in ways that passive learning through lecture cannot. Therefore, using simulation as an adjunct to lecture realistically helps students to bridge the theory–practice gap.

Small group simulations require a tremendous investment of faculty time and resources that are often scarce in the academic world. However, simulation as a complement to a larger group lecture integrates the benefits of learner-centered activity with the existing limits of resources. The student evaluations were highly positive, indicating assimilation of learning from both lecture and simulation. This combination of teaching methods can be applied to other health-related fields such as nursing and pharmacy.

APPENDIX 1

- SimMan Mannequin, link box, compressor (or other compressed air source), and monitor. Other mannequin models, such as models from METI or Gaumard, may also be used.
- Laptop with simulation software and microphone headset connected to:
  - Link box via 9-pin serial cable; and
  - Monitor via USB cable (a USB extender is recommended).
  - Version 3.2 or higher is recommended for the Laerdal product.
- Vital signs display monitor placed on a side table next to the gurney.
- Scan converter to allow for projection of the patient monitor onto an LCD projector for optimal visibility in this setting.
- Intravenous fluid with tubing (including in-line stopcocks attached to 20 gauge IV catheter inserted in right arm and draining into a drainage tubing and bucket/reservoir.
- Drug syringes filled with water to be labeled as drugs.
- Syringe labels for Vecuronium, Rocuronium, Succinylcholine, Neostigmine, Edrophonium, Atropine, Glycopyrolate, Midazolam, Valium, Morphine, Fentanyl, Propofol, and Thiopental.
- Adult bag and mask.
- Macintosh 3 laryngoscope and styletted 7.5 endotracheal tube with cuff syringe.
- ECG cable attached to simulator and secured to the back of the monitor.
- Noninvasive blood pressure cuff on left arm.
- Patient gown, linens, pillow.
- Patient gurney and IV pole.
- Airway lubricant.
- Nasal and oral airways (as well as other airway adjuncts).
- Stethoscopes, white laboratory coats, and gloves for participants.
- Duct tape or floor cable protectors to secure cabling.

APPENDIX 2

Limited Sampling of Written Comments (Edited for Spelling Only)

1. Include more teaching methods like this one. It helps to learn the correct way of thinking about these subjects. Multisystem effects for certain drugs can't be taught by teaching the items separately. It is important to integrate ALL the factors like this.
2. Wonderful . . . would like more time to work with simulation education. It allows timely response (regarding need to think on the fly) and greater understanding to basic curriculum.

3. Hands-on learning is a very valuable addition to lectures. It solidifies our textbook knowledge and gives us a chance, to put it into real-world context!
4. Patient, calm, supportive (positive) instructions helped a lot! Simulation education is key - I learn/remember more from 1 hour of simulation education than multiple hours of lecture/self study.

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