Improving Malignant Hyperthermia Education for the Non-Operating Room Environment Through High-Fidelity Simulation: A Quality Improvement Project

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Abstract

BACKGROUND: Malignant hyperthermia (MH) is a rare medical crisis that carries a dramatically decreased mortality rate when treated promptly. Training is not routine in the non-operating room anesthesia (NORA) setting. As NORA is becoming more prevalent, NORA clinical staff must have the appropriate training to respond to this emergency.

PURPOSE: The purpose of this quality improvement (QI) project was to improve the education of NORA clinical staff in the identification and management of MH. A secondary aim was to identify local institutional barriers in responding to an MH crisis and thus revise the standard operating procedures (SOP) accordingly.

METHODS: This project occurred at a single-center acute care medical facility. A total of 69 registered nurses, licensed practical nurses, and technicians participated in ten high-fidelity in situ MH simulations. Staff education was evaluated using pre- and post-simulation knowledge quizzes. Staff confidence surrounding MH was evaluated through Likert self-evaluations, debriefings, and thematic analysis. Simulations were observed to guide changes to the SOP.

RESULTS: Participants' mean knowledge quiz scores improved from 60% to 89% post-intervention ($p<0.001$). Mean Likert scores improved from 2.6 to 4.4 pre- and post-simulation respectively ($p<0.001$), demonstrating a significant improvement in confidence in the management of MH. Qualitative feedback identifying barriers in the MH response guided appropriate changes to the SOP.

CONCLUSION: High-fidelity, in-situ simulation was an effective method to improve NORA staff education and make meaningful improvements to the facility's MH SOP. Expansion of MH training into NORA areas presents a potential QI opportunity for other institutions to explore.

Keywords: NORA, non-operating room anesthesia, malignant hyperthermia, simulation

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Problem Description

Malignant hyperthermia (MH) is a rare, yet potentially devastating hyper-metabolic syndrome that may be triggered by either potent halogenated anesthetic gases or by succinylcholine, a depolarizing neuromuscular blocker (Rosenberg et al., 2015). After the diagnosis of MH is made, intravenous administration of dantrolene serves as the gold standard in treatment. Early detection and treatment with dantrolene dramatically decreases the mortality of MH (MHAUS, 2022a). Supplementary treatment of MH includes addressing metabolic acidosis, hyperkalemia, rhabdomyolysis, and hyperthermia (Brandom & Callahan, 2015).

MH poses a challenge for providers in the non-operating room anesthesia (NORA) setting, as patient outcomes are predicated upon prompt recognition, early treatment, and efficient teamwork to reduce patient mortality. MH training is not routine in the NORA environment. As anesthesia delivery continues to expand into the NORA areas, ensuring that NORA clinical staff has appropriate training to respond to MH is essential. The NORA setting presents unique challenges, such as the remoteness of their location, lack of anesthesia support staff, and small workspaces (Walls & Weiss, 2019). The restricted workspace of many NORA units also poses an obstacle for the large quantity of personnel required to respond to an MH emergency. Life-threatening events such as MH are complicated scenarios to maneuver, and the NORA environment can amplify these difficulties for staff.

Malignant Hyperthermia Association of the United States (MHAUS) guidelines state that dantrolene should be available within 10 minutes of the decision to treat MH (MHAUS, 2022b), but it is unknown if this location's NORA departments have the capability to retrieve the MH cart within this timeframe. If necessary, an additional MH cart would be procured to meet MHAUS recommendations at this institution; however, dantrolene (Ryanodex) is a cost-prohibitive drug, and having a single MH cart is preferable for many institutions. While online training modules are assigned to local NORA staff at this institution, there is an opportunity for more comprehensive training addressing the emergency response to MH. Lastly, there is an absence of cognitive aids addressing MH in NORA areas at this location.

An internal review identified a lack of individualization of standard operating procedures (SOP) for MH to the acute care medical facility's NORA environments. Items within the SOP requiring clarity included: identifying the proper individuals and/or departments to notify in the event of an MH crisis, outlining the process of obtaining the MH cart located within the OR core, and defining more clearly defined roles during an MH episode. As NORA is being performed more frequently at this institution, delineating these challenges provides an opportunity to improve the emergency response to MH within this context. Certified registered nurse anesthetists (CRNAs) and student registered nurse anesthetists (SRNAs) are well-equipped with the skills and knowledge to address these challenges through quality improvement (QI) initiatives.

Available Knowledge

While education in MH crisis training is commonplace in the operating room (OR) setting (Cain et al., 2014; Matsco et al., 2020; Parsons et al., 2020), there is a lack of literature specifically addressing MH education for the NORA environment. This is likely because NORA is a relatively new and rapidly growing field (Walls & Weiss, 2019). However, it is generally accepted that standards for availability of equipment, medication, and monitoring in NORA areas should be held to the same standard as in the OR (Herman, 2021). Thus, education in the treatment of MH should be no exception. A review of the literature identifies interventions such as interdisciplinary simulation, cognitive aids, and unit champions to be evidenced-based strategies to address this problem at this institution.

Using In Situ Simulation to Improve Quality

Simulation has the power to provide a safe opportunity to practice high-risk clinical scenarios that would otherwise be rarely encountered in practice (Lamé & Dixon-Woods, 2020). The American Association of Nurse Anesthesiology (AANA) (2018) and MHAUS (2022c) recommend annual interdisciplinary MH crisis team training, such as mock drills and simulation to improve the response to MH. Team crises training is useful for individuals who are relatively unacquainted with the intricacies of the NORA work environment by building familiarity and cohesion (Herman et al., 2021). However, the retention of crisis management skills over time remains to be understood (Fung et al., 2015).

More recently, simulation is being used as a technique to supplement QI in healthcare (Lamé & Dixon-Woods, 2020). In situ simulation takes place in one's actual clinical environment, rather than a simulation center. In situ simulations have the potential to uncover institutional weaknesses by "testing the system." By identifying gaps in system processes, policy can then be evolved accordingly. Furthermore, interdisciplinary in situ crisis training is an alluring option for institutions without simulation centers (Kurup et al., 2017). A common drawback of in situ simulations is the requirement of additional resources and manpower required versus a traditional simulation lab (Patterson et al., 2008). For example, the simulator must be transportable, making high-fidelity simulation impractical for all institutions (Patterson et al., 2008). For these reasons, in situ simulations are often best accomplished at larger institutions (Patterson et al., 2008).

Cognitive Aids

The incidence of MH is estimated to be about 1:100,000 surgeries in adults (MHAUS, 2022e). Given the rarity of MH, there is often a lack of comfort in recognizing and treating MH in an appropriate and timely fashion. Cognitive aids can reduce the cognitive load in crisis situations through prompts that help users effectively complete a sequence of complex tasks (Marshall, 2013). Cognitive aids can take a variety of forms, such as protocols, checklists, algorithms, or posters. The MH cognitive aid developed by MHAUS is one of the first cognitive aids to be used in anesthesia practice (Pinyavat et al., 2014). This widely distributed poster provides an eye-catching algorithm that is straightforward and easy to follow and is thought to increase the timely and efficient response to MH (AANA, 2018; MHAUS, 2022d). The MHAUS cognitive is often integrated into simulation-based scenarios (Pinyvat et al., 2014). Cognitive aids are thought to be more effective through reinforcement by a unit "champion" (Borshoff & Sadleir, 2020).

Unit Champions

An integrative review of the literature found champions to be an essential component of a successful implementation project (Miech et al., 2018). These individuals help to drive improvement projects forward by familiarizing staff with the cognitive aids, providing motivation and training, and encouraging feedback from NORA personnel (Borshoff & Sadleir, 2020). Traits of effective champions include having a passion for the project's success, effective communication and education skills, respect amongst peers, and effective teamwork (Miech et al., 2018). While there are no reported adverse effects in using champions, the opportunity cost of using champions should be considered before implementation (Santos et al., 2022).

Specific Aims

The purpose of this QI project was to educate NORA clinical staff in the identification and timely response to MH. This was accomplished through the creation of a robust annual high-fidelity in situ simulation training program. The secondary aim was to utilize simulation to identify process changes for this facility's SOP surrounding MH in the NORA departments.

Rationale

This project was guided by the Model for Improvement (MFI) framework (Associates in Process Improvement, 2022). The MFI is a tool used to accelerate improvement through a two-part process. A cause and effect diagram was constructed to help identify areas for improvement (see Appendix A). Aims, measures, and changes were then identified to guide the improvement process. Plan-Do-Study-Act (PDSA) cycles were then used to test if interventions resulted in improvements. This model was chosen for its ability to provide a clear and structured plan to guide the researchers through the steps of a successful QI project. The PDSA framework allowed for adaptability, as incremental changes to simulation and protocols were evaluated for effectiveness after each iteration.

A high-fidelity in situ simulation intervention was chosen, as it allows for the analysis of emergency readiness, availability of equipment, interdisciplinary workflow, and adherence to institutional policy. In addition, simulation-based training has been associated with significant improvements in learning outcomes as compared to traditional, didactic, or case-based teaching (Fung et al., 2015). It was hypothesized that in situ simulation would achieve both project aims by providing a more immersive educational environment in learner's home units while also uncovering systemic barriers to the MH response.

Methods

Context

This QI project took place at a single-center acute care medical facility in the Northwestern United States. The impetus for this project arose from a site visit by the Health Care Quality Accreditation, a group contracted by the facility to assess institutional compliance in healthcare. Surveyors identified deficiencies in the understanding of MHAUS treatment guidelines and the facility's MH SOP within NORA departments. As there was a potential for an inadequate MH emergency response within NORA areas, a root cause analysis (RCA) was done by hospital leadership and the Quality, Safety, and Value (QSV) department. The RCA identified a need for education that provides a lasting and comprehensive understanding of the emergency response to MH. It was recognized that current online MH educational modules did not fulfill this goal. Thus, hospital leadership approached the authors requesting a QI initiative to address this problem (see Appendix B for more information on Project Timeline).

An interprofessional team was formed to include the hospital's CRNA educator, two SRNAs, a perioperative services clinical nurse leader, a simulation coordinator, and unit champions. Hospital leadership and department managers were also consulted in the creation of this QI initiative. Simulation participants included registered nurses (RNs), licensed practical nurses (LPNs), and technicians. This intervention included five departments in total. Four departments where NORA was performed at this facility included interventional pulmonology, gastroenterology, radiology, and electrophysiology. Because MH may occur in the recovery period following NORA, the phase II recovery unit was also included in the interventions.

Interventions

Prior to the authors' interventions, the perioperative services clinical nurse leader initiated numerous interventions that helped to ensure success of this project. Early revisions of the institution's SOP were made to incorporate NORA areas. The nurse leader developed a simulated MH cart, which included simulated dantrolene (Ryanodex) in addition to items supplied in the institution's existing MH cart. Lastly, MHAUS MH treatment guideline posters were distributed to NORA units prior to commencement of the simulations.

Upon initiation of this project, two simulation outline templates (see Appendix C) were developed, one for NORA locations, and one for phase-II locations. Outlines were utilized to maintain consistency between simulation sessions. The outline detailed learning objectives, necessary equipment, simulation leader roles, simulation leader cues, manikin vital sign changes, and criteria for termination of the simulation. Role cards were developed as a method to reduce the cognitive load for participants during the simulation (See Appendix D). Role cards included the title of the individual role, as well as a succinct description of the participant's responsibilities during the emergency. The simulation was modeled after the institution's SOP and MHAUS treatment guidelines. The simulation was terminated once all steps of the MHAUS cognitive aid poster were completed (MHAUS, 2022d).

Nine MH simulations were held in situ, with one simulation held in the institution's simulation center due to scheduling-related reasons. Each simulation session lasted one hour. Sessions began with a pre-quiz that was followed by a 10-minute education session. Educational handouts were also administered at this time. A five-minute pre-brief and simulation orientation followed which included a brief orientation to the simulated MH cart. The simulations ran for an average duration of 10 minutes and utilized a high-fidelity, full-size manikin, along with a simulated patient monitor displaying continuous vital signs. The manikin operator was given a copy of the simulation outline to allow for real-time reactions to participant interventions. For example, a scripted improvement in vital signs occurred after the administration of dantrolene (Ryanodex). Many of these changes were pre-programmed by the manikin operator. An SRNA played the role of team crisis leader, a CRNA educator played the role of proceduralist, and an additional SRNA played the role of a CRNA called in to help. The director of simulation services operated the high-fidelity manikin, and the perioperative services clinical nurse leader supervised the simulated MH cart circa its usual storage location.

Each simulation began with a procedure common to the department in which it was held. Upon initiation of the simulation, vital sign changes suggesting MH were displayed. Once MH was identified, the team crisis leader delegated roles to participants. Individual responsibilities were represented on physical role cards which were handed out to participants. Delegated responsibilities included retrieval of the MH cart, retrieval of the code cart, event recording, retrieval of ice, administration of medications, and notification of appropriate entities (see appendix D.

Participants were encouraged to read from the MHAUS cognitive aid poster to ensure all steps of the treatment algorithm were followed. After completion of the simulation, a twenty-minute structured debriefing and question and answer period followed. The session ended after completion of post-simulation knowledge quizzes and Likert self-evaluations.

Study of the Interventions

To measure the impact of the initiative on improving education, a one-tailed, paired t-test was applied to pre- and post-simulation anonymous knowledge quiz scores to assess for a statistically significant change in staff knowledge surrounding MH recognition and treatment.

Knowledge quiz content was based on MHAUS MH treatment guidelines and the facility's SOP. Quizzes were administered directly before and after the intervention to assess the intervention's effect on participants' knowledge of MH. Unanswered and improperly completed questions were excluded from the data analysis. A one-tailed, paired t-test was also applied to Likert scale self-evaluations to evaluate for a statistically significant change in perceived confidence surrounding MH recognition and treatment. To increase the statistical power of the analysis and to reduce the impact of individual variation within departments, all t-tests were averaged amongst departments. Qualitative feedback was gathered anonymously from an open-ended section of the self-evaluations and via feedback from structured simulation debriefings. Self-evaluation forms contained sections for pre- and post-simulation readiness and comfort with MH treatment, which aimed to ascertain if observed results were due to the intervention. Feedback was thematically analyzed for potential improvements to the simulation program and to guide improvements to the MH SOP.

Measures

Interventions were evaluated through outcome measures, process measures, and balancing measures (Institute for Healthcare Improvement, 2022). Outcome measures include improvement in MH knowledge quiz scores, improvement in NORA staff confidence measured through self-evaluation Likert scores, and updated SOP guidelines specific to the NORA departments. Process measures include survey completion rates, adequate resources for the MH response, time to retrieve the MH cart, and on-time completion of simulations. Balancing measures include the availability of time to facilitate annual MH simulations, disruption of staff workflow including patient-care-related activities, and the availability of clinical areas to run in situ simulations.

Analysis

Data were collected via the following methods: pre- and post-simulation knowledge quizzes (see Appendix E1) and post-simulation Likert-scale self-assessment surveys (see Appendix G1) as well as post-simulation group debriefing sessions. Quantitative data, encompassing pre- and post-simulation quiz scores, were collected to evaluate outcome measures.

Assessment and graphical representation of data were performed in Microsoft Excel. A one-tailed, paired t-test was applied to assess for a statistically significant change in mean scores of pre- and post-simulation knowledge quizzes and pre- and post-simulation Likert-scale self-evaluations. A bar graph was constructed to visually represent the change in mean knowledge quiz scores and improvements in self-assessment surveys.

Qualitative data was collected through voluntary interviews with NORA staff at the commencement of each simulation. Staff concerns, especially those not evidenced through the self-assessment surveys were analyzed individually, and themes in responses were identified to recognize opportunities to improve upon MH simulations.

Ethical Considerations

Both a university and a facility Institutional Review Board (IRB) reviewed this QI project and determined that ethical guidelines of the project conform to each organization's standards. This project did not require collection of patient health information (PHI), nor did it involve human subjects research. No personal information was collected from MH simulation participants. Responses from questionnaires were anonymous and corresponding data were stored via encrypted cloud storage. Participants were free to leave MH simulation sessions at any time. The authors have no have no conflicts of interest to report.

Results

Quantitative Results

A total of 69 individuals participated in the 10 simulations. Pre- and post-simulation knowledge improved from 60% to 89%, respectively (n=58 and n=66) (see Appendix E2). T-test analysis found these results to be statistically significant ($p<0.001$). Blank or improperly answered questions were omitted from the analysis; however, this did not affect the significance of the results. Certain knowledge quiz topics showed noticeable improvements post-simulation, as there was a 315% increase in correct answers on dantrolene (Ryanodex) reconstitution and a 266% improvement in correct answers regarding the MHAUS timeline for retrieving the MH cart which contained dantrolene (Ryanodex). Following the simulation exercise, 98% of participants could correctly identify the MH cart location on a four-option multiple-choice question, as opposed to 64% pre-intervention, demonstrating a significant improvement to an important aspect of the MH response ($p<0.001$).

Likert self-evaluations showed a statistically significant improvement in participants' personal comfort in the recognition and treatment of MH ($p<0.001$) (see Appendix F2). Generally, participants agreed that they felt better prepared to recognize the signs and symptoms of MH, knew who to notify in the event of an MH crisis, understood the process for retrieving the MH cart, and gained knowledge surrounding the pharmacologic and physiologic treatment of MH.

All departments were successful in having simulated dantrolene (Ryanodex) available at bedside within the recommended 10-minute guideline set forth by MHAUS. For all sites where

NORA staff would typically retrieve the MH cart, the cart was brought to bedside in less than 7 minutes, and simulated dantrolene (Ryanodex) was administered in less than 8 minutes (see Appendix G).

Qualitative Results

Qualitative feedback from free-text portions of self-evaluation questionnaires and group debriefings were evaluated for common themes (see Appendix H). Participants responded with an overwhelmingly positive response to the simulation sessions, with one technologist stating the most valuable part of simulation being, “Knowing who to call, where to find required materials and equipment and that calling a code is acceptable!” Themes of positive self-reflection regarding simulation learning and performance were balanced with recognition of various obstacles encountered during simulation. While closed-loop communication was emphasized to be effective by multiple simulation participants, the unfamiliarity with supplies and equipment were also a common concern.

Some simulation participants desired greater preparation prior to simulation, such as a more in-depth review of the MHAUS algorithm or a visit to the MH cart in the OR. Process improvement measures were suggested during debriefings, as several participants requested simulation role cards be adopted for actual use within NORA sites. Reading weight-based dosing guidelines on the MH cart was a challenge for some participants, which slowed the time to administration of dantrolene (Ryanodex). The absence of insulin syringes in one NORA unit was a concern raised by the staff after it was found to be unavailable during a simulation. This obstacle was found to delay the treatment of a simulated life-threatening hyperkalemia. Unit staffing concerns were also raised, with one respondent stating, “After hours staffing is an issue. Might be no nurses.” This comment is of particular importance, as technologists do not typically administer medications at this institution, and this would impede the timely execution of life-saving treatments in the MH response.

Process Changes as a Result of Data

The institution's SOP was amended as a direct result of these educational sessions (see Appendix I). Because participants were successful in retrieving dantrolene (Ryanodex) within the 10-minute timeframe recommended by MHAUS guidelines, it was determined that a single MH cart would be appropriate for this facility. Due to participant feedback, role cards were hung in proximity to the MH treatment crisis poster in NORA units to potentially reduce the cognitive load in the event of an actual MH crisis. Alternating row highlights on the dantrolene (Ryanodex) weight-based dosing guide were added to the MH cart binder for ease of readability. Additionally, amendments to the SOP were made to ensure a stock of IV insulin syringes in the MH cart, which allowed for a quicker response to the simulated hyperkalemia. Because of the limited staffing in NORA areas, the local SOP was amended to encourage calling a code overhead in the event of an MH emergency.

Discussion

Summary

The simulation intervention led to a significant improvement in the education of NORA staff in the identification and timely response to MH at this facility. The high-fidelity in situ nature of the simulation was crucial in identifying opportunities to improve the hospital's SOP surrounding MH. There were several important strengths specific to this QI project. The immersive nature of simulation lent to a positive reception by NORA staff and was a notable improvement upon the existing didactic online MH modules. Consistency in findings between the quantitative and qualitative sources contributed to the strength of the project's results. To the authors' knowledge, this is the first published QI project addressing MH education within NORA areas.

Interpretation

Following the intervention, participants demonstrated significant improvements in their understanding of the MH emergency response through improvements in knowledge quiz scores. Simulation participants also expressed increased comfort in the recognition and treatment of MH. Numerous responses through self-evaluations and group debriefings attributed these improvements to the high-fidelity in situ simulation sessions.

Improvements in participants' knowledge and comfort in the MH emergency response are consistent with other QI projects surrounding MH simulation (Cain et al., 2014; Matsco et al., 2020; Parsons et al., 2020). However, the focus of other QI projects surrounding MH education typically involves OR personnel rather than NORA personnel. Our findings are consistent with Cain et al. (2014), as improved role clarity and teamwork were emphasized by NORA staff post-intervention. Similar to Matsco et al. (2020), feedback from participants were also majorly positive, citing visualization of workflow and role clarity as crucial aspects of simulation.

The nature of the intervention was sufficient to result in a positive outlook on MH educational efforts at the end of each session by virtually all participants. Participants expressed that the simulation had a structured and understandable format. The immersion of in situ simulation was emphasized repeatedly by simulation participants. Responses from participants reflect that high-fidelity in situ simulation is a valuable educational adjunct for this facility. Additionally, simulation was crucial in individualizing the MH SOP to include language specific to NORA areas.

Limitations

This QI project included several limitations. First, knowledge retention over time was not studied. For example, it is known in basic life support training that skills have been shown to deteriorate in three to six months after training (Kovács et al., 2019). Renewal training has been reported to improve retention (Kovács et al., 2019), and annual MH training is recommended by MHAUS (2022c) and the AANA (2018). The data is also limited by the "practice effect" in which the second test attempt may improve the retrieval of memories. This phenomenon has been shown to occur even in the absence of post exam feedback (Kovács et al., 2019). The generalizability of this QI project is limited by the resources required to run such a program. Running a high-fidelity simulation requires multiple personnel, a high-fidelity simulator, and the resources to develop a simulated MH cart. This could prove costly for some institutions. Finally, research shows that the sustainability of QI projects to be generally low. Repeatability of the intervention not only depends upon buy-in from hospital leadership, but also by departmental MH champions who will be responsible to run future MH simulations at this institution. Future projects could focus on the sustainability of such a program in the long term. Finally, trainings will be held by individual departments separately. This opens the potential for inconsistent annual training between departments. Future efforts could investigate this potential issue.

Conclusions

High-fidelity in-situ simulation was an effective method to improve NORA staff education surrounding the identification and timely treatment of a potential MH crisis at this facility. Simulations identified institutional barriers impeding the effective response to an MH crisis, and meaningful improvements to the institution's MH SOP were made. Future projects could explore the long-term sustainability of such an intervention and the retention of knowledge over time.

On a national level, NORA departments are not the traditional focus for MH training. However, as NORA continues to grow, it is essential that appropriate staff be educated for low-frequency, high-risk events. The authors have demonstrated that MH training was effective and well-received by NORA staff. While the focus of MH education traditionally resides within the OR environment, expansion of MH training into NORA areas presents a budding QI opportunity for appropriate institutions to explore.

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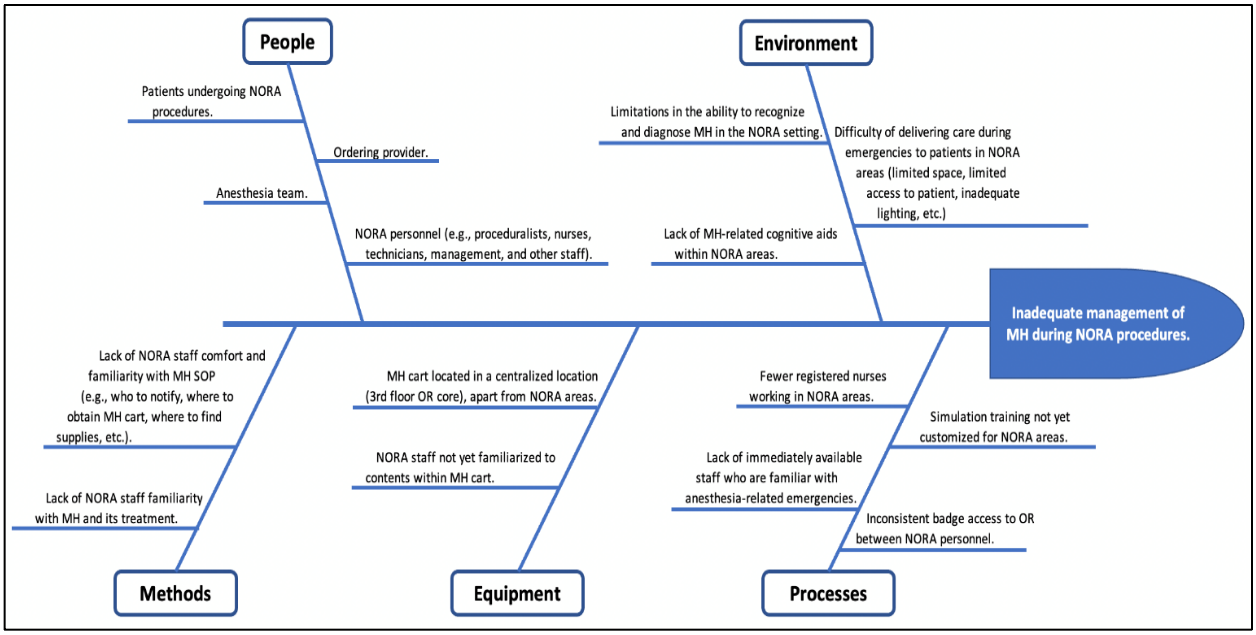
Appendix A

Cause and Effect Diagram



Appendix B

Project Timeline

	May 2022	Aug 2022	Sept 2022	Oct 2022	Nov 2022	Dec 2022	Jan 2023	Feb 2023	Mar 2023	Apr 2023	Jun 2023
Leadership Patient Safety Rounding Identified MH Educational Gap	X										
IRB determination of approval completed					X						
Project Creation		X	X	X	X	X					
Implementation: PDSA Cycle 1-6							X				
PDSA Cycle 7								X			
PDSA Cycle 8-9									X		
PDSA Cycle 10										X	
Final Data Analyzed										X	
Project Finalized for Dissemination											X

Appendix C

Sample Simulation Outline Format

Malignant Hyperthermia Simulation Outline (NORA Sites) 1

Sim Leader Roles	Learner Roles	Optional Sim Leader Roles:
1. CRNA to Function as MH Crisis Leader 2. 2nd anesthesia provider 3. Proceduralist 4. Simulation Operator (also records timing of events during simulation) 5. Staff to supervise MH Training Cart, cooled IV fluids, and regular insulin at OR Schedule Coordinator Office ("Cart Supervisor")	1. Staff to obtain "MH cart" 2. Staff to obtain "code cart" and record 3. Medication RN 4. Cooling staff 5. "Notifying" staff	1. Staff to answer simulated Vocera/phone calls 2. Pharmacist (use actual critical care pharmacist for ICU pathway) 3. SICU RN (optional pathway) **Reminder:** Notify recipients of "actual" phone calls ahead of time regarding this MH simulation.

Supplies:
Sign-in sheet, pens, pre/post simulation quizzes, self-evaluation questionnaire, "role cards," simulated ABG/laboratory results.

Simulated Vocera, Sim man, endotracheal tube, anesthesia breathing circuit x2, Ambu bag.

Simulated Code Cart (with code blue form).
Simulated MH Cart (with MH report form), simulated cold IV fluids, & simulated regular insulin.

Simulation Goal Time Frames	
Sign-in & Baseline Quiz	5 minutes
Purpose of Sim	3 minutes
Pre-Education	10 minutes
Sim Orientation	2 minutes
RUN SIMULATION	10 minutes*
Code 99 Debriefing and Q&A	20 minutes
Post-Sim Quiz & Self-Evaluation	5 minutes
Total Time	**55 minutes**

Learning Objectives
- List the signs and symptoms of malignant hyperthermia.
- Name who to notify in the event of a malignant hyperthermia crisis.
- Demonstrate prompt retrieval of malignant hyperthermia cart.
- Verbalize the pharmacologic and physiologic treatment of malignant hyperthermia.
- Optional: Demonstrate continuity of care for the MH patient, including patient transfer to ICU with ICU RN verbalizing understanding of continued ICU management of MH.

**Allow for additional simulation time if "optional ICU pathway" is utilized.*

Malignant Hyperthermia Simulation Outline (NORA Sites) 3

Pre-briefing Scenario:
*B. Tannen is a 65-year-old male with severe gastroesophageal reflux disease (GERD). He has no allergies. He is undergoing NORA Procedure of Choice. He is 100kg. He was intubated with **succinylcholine** and propofol, and he is receiving some **sevoflurane** for maintenance of anesthesia.*
- *Example NORA Procedures of Choice:*
  - *EP: A-fib ablation*
  - *GI: EGD for upper GI bleed*
  - *Bronch: Endobronchial ultrasound (EBUS) for cancer*
  - *CT: Hepatic microwave ablation (MWA)*
  - *MRI: Full body scan with contrast for claustrophobic patient*
  - *IR: Hepatic stent*

Baseline simulator state
Patient Status: Lying flat, eyes closed, unresponsive to stimulus.
Props: Wearing a gown, endotracheal tube (ETT) in place, anesthesia circuit attached to ETT, x1 IV in arm.
Sinus rhythm @ 78 BPM
130/70
SpO2 99% on 40% FiO2
RR 16
36.8 C
ETCO2 40 mmHg

Trigger: Once simulation starts
Action: Vital signs immediately start changing to:
Sinus tachycardia @ 120 BPM
175/110
SpO2 87% on 40% FiO2
RR 30
37.8C (Temperature will continue to rise to 39.2 over an additional 4 minutes)
ETCO2 60 mmHg

Trigger: If any events on "Simulation Event Timeline" form occur, such as Decision to treat MH is made, Code blue cart brought to the room, MH Cart brought to room, Dantrolene given, etc. occur.
Action: Please record these times on the "Simulation Event Timeline" form (*ask coordinator of the MH simulation for this form*).

Malignant Hyperthermia Simulation Outline (NORA Sites) 5

The 5 roles will be assigned as follows:

"Staff to obtain MH Cart, etc."
- Retrieve simulated **MH cart, cold IV fluids, and regular insulin** from OR Schedule Coordinator office.
- If staff attempts to call any of: the OR Schedule Coordinator, PACU Charge RN, or ICU Charge RN, none of these persons will be able to retrieve the MH cart, and the NORA staff member will need to retrieve the cart themselves.

"Staff to obtain Code Cart and Record"
- Retrieve the **Code Blue Cart**.
- May temporarily record timeline of interventions and dosages of medications on Code Blue Form until MH cart arrives.
- **MH Report Form** is on the MH Cart in a binder. Once MH Report Form is available, records the following on this form:
  - Time of MH diagnosis
  - Dantrolene (RYANODEX®) dose administered
  - Any other medications given
  - Nursing interventions including cool down methods
  - IV lines/catheters inserted

"Medication RN"
- Calculates dose needed for dantrolene (Ryanodex) or contacts Pharmacy to dose.
- Mixes and administers dantrolene (Ryanodex) to patient.
- Administers 50 mEq (1 ampule) of bicarbonate (found on code cart or MH cart), when ordered by anesthesia provider.
  - May give in the absence of labs
  - Give while waiting for MH cart
- Administers any medications ordered by anesthesia provider, such as:
  - Hyperkalemia treatment
  - Arrythmia treatment

"Cooling"
- Cools hyperthermic patient (needed if core temperature >39C; stop cooling once temperature reaches <38C) by implementing cooling measures such as:
  - Retrieves ice from nearest ice machine to be bagged and placed on patient's neck, groin, & axilla.
  - If ice not immediately available, assembles cold packs from MH cart and places on patient's neck, groin & axilla.
  - Administers cold IV fluid.
  - Inserts irrigating foley catheter to perform cold continuous bladder irrigation.

Malignant Hyperthermia Simulation Outline (NORA Sites) 7

Trigger: Potassium level is announced
Action: EKG shows widened QRS complex, frequent PVCs, and "peaked T waves"

Trigger: Insulin is given
Action: EKG normalizes as QRS complexes become narrow (normal), PVCs disappear, and "peaked T waves" disappear. Rhythm becomes sinus tachycardia @ 105 BPM.

The CRNA will request a simulation participant to review the MHAUS algorithm (poster on cart or wall) out loud to confirm that proper treatment was delivered. The following are confirmed:
1. MH Cart was retrieved and 2.5mg/kg Dantrolene was administered.
2. Bicarbonate was administered.
3. Cooling measures were instituted.
4. MHAUS MH Algorithm was completed.
5. Appropriate personnel were notified: MHAUS, Pharmacy, OR schedule coordinator, and ICU charge RN.

End of simulation **OR** **Optional ICU Pathway on Next Page**

STOP

Appendix D

Role Cards

STAFF TO OBTAIN MH CART, etc.	• Retrieve simulated **MH cart, cold IV fluids, and regular insulin** from OR Schedule Coordinator office. • Note: In an "actual" emergency, the **MH cart** will be retrieved from the OR core on the 3rd floor. **Cold IV fluids** and **regular insulin** are located in the OR core's refrigerator. • Note: In an "actual" emergency, any of the following persons may be called to retrieve the above items: o OR Schedule Coordinator o PACU Charge RN o ICU Charge RN (if above unsuccessful)
MEDICATION RN	• Calculates dose needed for dantrolene (Ryanodex) or contacts pharmacy to dose. • Mixes and administers dantrolene (Ryanodex) to patient. • Administers 50 mEq (1 ampule) of bicarbonate (found on code cart or MH cart), when ordered by anesthesia provider. o May give in absence of labs o Give while waiting for MH cart • Administers any medications ordered by anesthesia provider, such as: o Hyperkalemia treatment o Arrhythmia treatment
COOLING STAFF	Cools hyperthermia patient (needed if core temperature >39C; stop cooling once temperature reaches <38C) by implementing necessary cooling measures such as: • Retrieves ice **from nearest ice machine** to be bagged and placed on patient's neck, groin, and axilla. • If ice not immediately available, assembles cold ice packs from MH cart and places on patient's neck, groin, and axilla. • Administers cold IV fluid. • Inserts irrigating foley catheter to perform cold continuous bladder irrigation. • Implements other cooling measures such as inserting rectal tube, orogastric (OG) tube, etc., for cold lavage.

<table>
<tr>
<td>STAFF TO OBTAIN CODE CART
AND RECORD</td>
<td>

Retrieve the <u>Code Blue Cart.</u>
May temporarily record timeline of interventions and dosages of medications on Code Blue Form until MH cart arrives.
MH Report Form is on the MH Cart in a binder. Once MH Report Form is available, records the following on this form:

Time of MH diagnosis
Dantrolene (Ryanodex) dose administered
Any other medications given
Nursing interventions including cool down methods
IV lines/catheters inserted

</td>
</tr>
<tr>
<td>NOTIFYING STAFF</td>
<td>
<table>
<tr><th colspan="4">Who To Notify in a Suspected MH Crisis</th></tr>
<tr><th>Who</th><th>Vocera</th><th>Extension</th><th>Why</th></tr>
<tr><td>OR Schedule Coordinator
(and/or PACU Charge RN)</td><td>“Call OR schedule coordinator”</td><td>x59905
x56041</td><td>Will alert the anesthesiologist of the day (AOD).

If available, can assist in obtaining MH cart.</td></tr>
<tr><td>ICU Charge RN</td><td>“Call ICU charge nurse”</td><td>x55056</td><td>For bed placement and to request ICU RNs, if needed.

If available, can assist in obtaining MH cart.</td></tr>
<tr><td>Pharmacy</td><td>“Call inpatient pharmacy”</td><td>x55535</td><td>Will assist with dosing, mixing and administration of dantrolene. If necessary, will obtain additional supply of dantrolene.</td></tr>
<tr><td>MHAUS MH Hotline</td><td>“Call outside line”</td><td>1-800-644-9737

(Recommended)</td><td>Will assist providers in real time with managing an MH crisis.</td></tr>
</table>
</td>
</tr>
</table>

Appendix E1

Pre- and Post-Simulation Knowledge Quiz

1. Malignant hyperthermia (MH) is a **hypermetabolic** syndrome that may be triggered by either volatile **anesthetic gases** (e.g., sevoflurane, isoflurane, or desflurane), or by **succinylcholine** (a “depolarizing” paralytic).
    a. True
    b. False

2. Nitrous oxide (N2O) is a known trigger of malignant hyperthermia.
    a. True
    b. False

3. Signs of MH may include (**Choose 2**):
    ☐ Muscle rigidity
    ☐ Hypothermia
    ☐ Increased end-tidal CO2
    ☐ Bradycardia

4. Which of the following actions are helpful during an MH crisis? (**Select all that apply)**:
    ☐ Immediately turning off all volatile anesthetic gases.
    ☐ Referencing the Malignant Hyperthermia poster in room.
    ☐ Obtaining the MH cart.
    ☐ Administering cooled intravenous fluids.
    ☐ Using ice packs to cool the patient.
    ☐ Administering dantrolene.

5. During an MH crisis, overall direction and the assignment of roles will be provided to staff by:
    a. The proceduralist.
    b. The pharmacist.
    c. The anesthesia team.
    d. The charge RN.

6. You are assigned to obtain the MH cart during an MH crisis. Where is the MH cart located?
    a. 3rd floor OR core.
    b. Pharmacy.
    c. Within each out-of-OR location.
    d. PACU.

7. The MH cart should be obtained within ____ of recognition of MH.
    a. 5 minutes
    b. 10 minutes
    c. 30 minutes
    d. 60 minutes

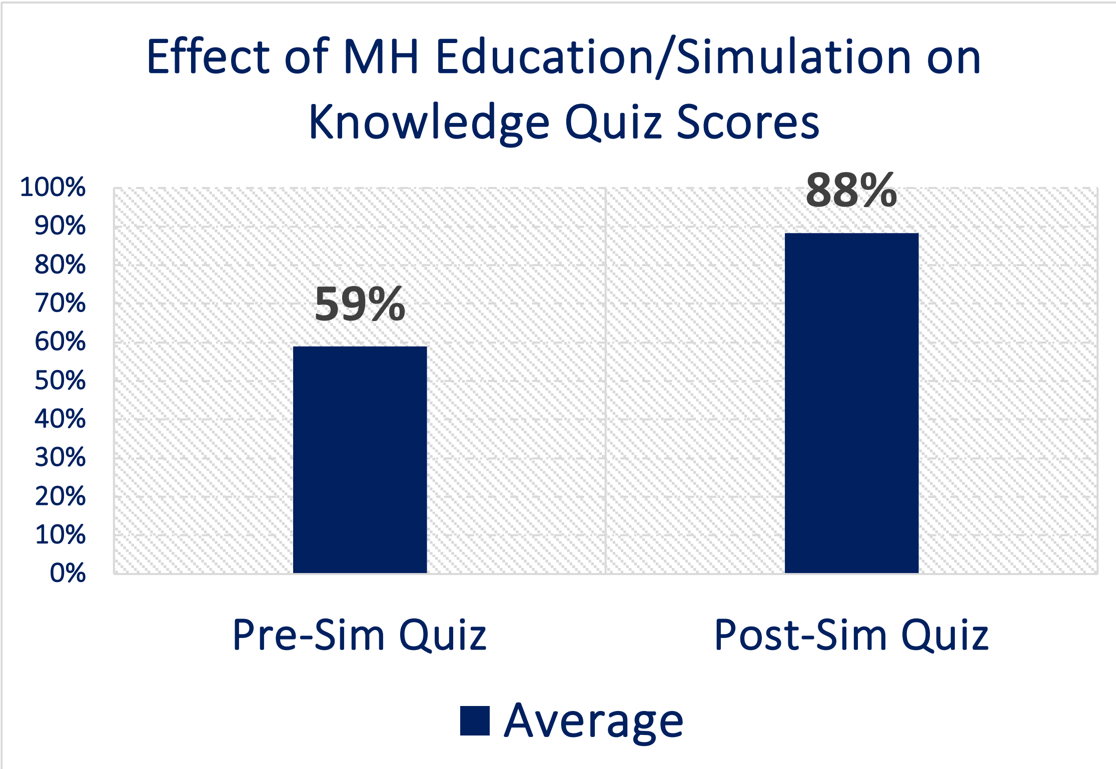
8. Aside from personally obtaining the MH cart, the cart can also be obtained by calling which of the following **3** individuals? (**Choose 3**)
    ☐ OR schedule coordinator
    ☐ PACU charge RN
    ☐ ICU charge RN
    ☐ ER charge RN

9. During an MH crisis, **pharmacy** should be contacted, and a team member will be assigned to call the **Malignant Hyperthermia Association of the United States** (MHAUS).
    a. True
    b. False

10. How is each 250mg vial of dantrolene (Ryanodex) reconstituted?
    a. With 5 mL of sterile water.
    b. With 10 mL of sterile water.
    c. With 5 mL of normal saline.
    d. With 10 mL of normal saline.

Appendix E2

Knowledge Quiz Results



Appendix F1

Likert Self-Evaluation Questionnaire

	Prior to MH Simulation					As a Result of MH Simulation				
Questions	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
	1	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
I am prepared to recognize the signs and symptoms of MH										
I know who to call in the event of an MH crisis.										
I am familiar with the location of the MH cart and its contents.										
I am knowledgeable of the pharmacologic and physiologic treatment of MH.										
I found this simulation to be beneficial.	N/A	N/A	N/A	N/A	N/A					

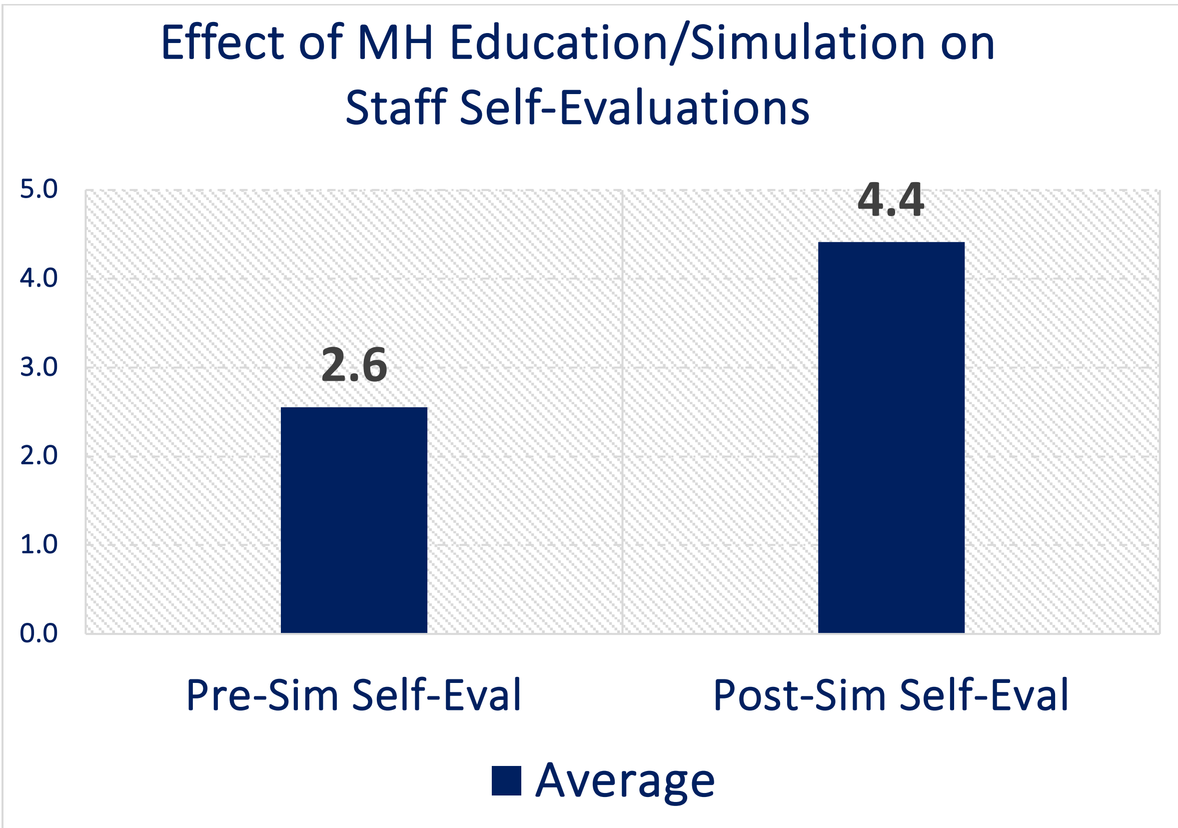
Title (RN, LPN, CNA, tech, etc.): _____________________

What were the most valuable parts of this learning experience?

What can we change to improve this learning experience?

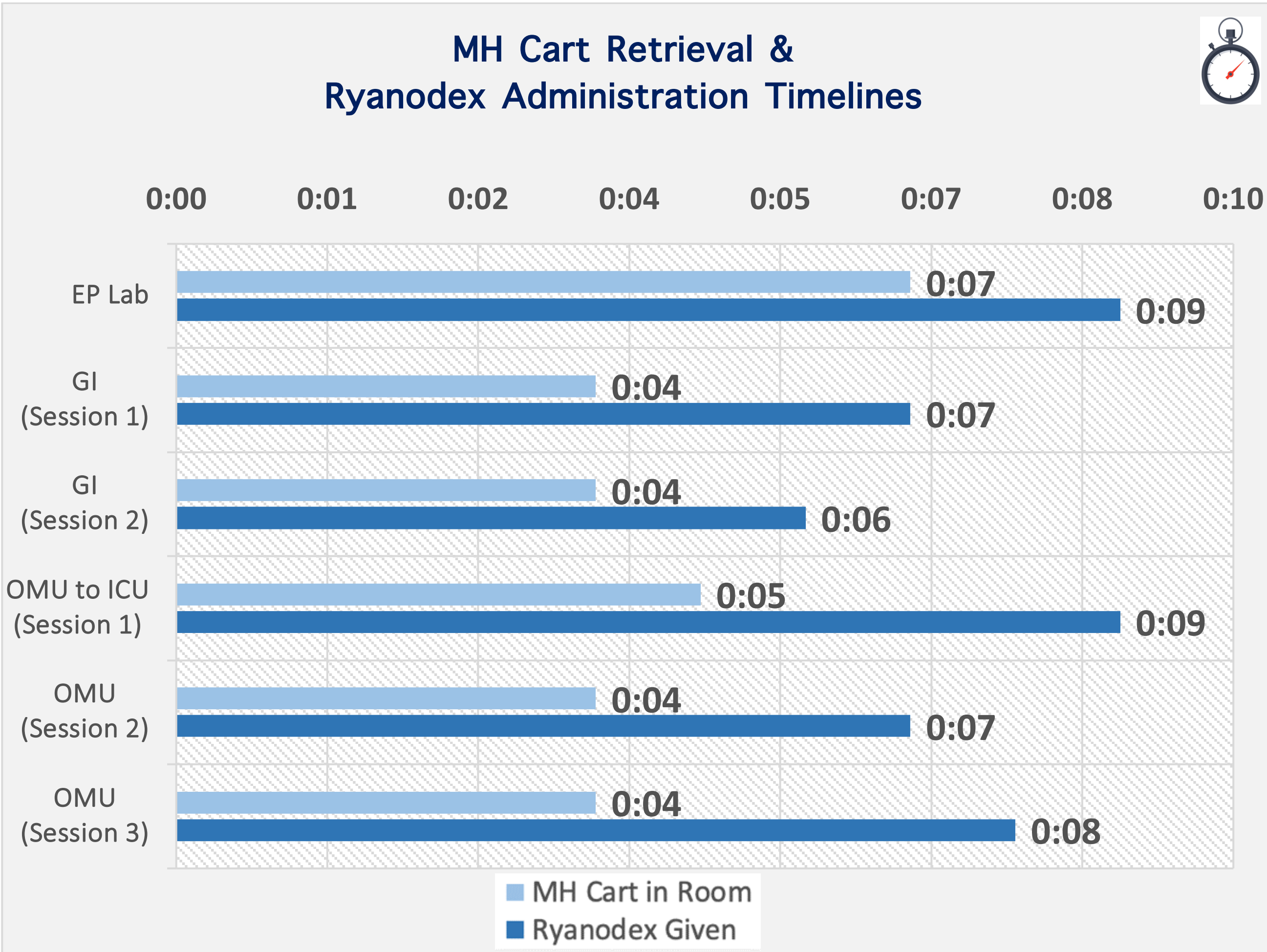
Appendix F2

Likert Self-Evaluation Questionnaire Results



Appendix G

MH Cart Retrieval & Ryanodex Administration Timelines



Appendix H

Thematic Analysis

Theme (total responses)	Code (total responses)	Examples
Positive experiences with activity (64)	Simulation was valuable (47)	Tech: "Knowing who to call, where to find required materials and equipment and that calling a code is acceptable!" Tech: "All of it. We really haven't experienced it here in CT so I'm grateful for the information in case it happened some day. I thought it was very informative. Thank you. :)"
	Being educated on MH emergency roles was valuable (9)	Tech: "I had no idea what MH was, but this was very useful. Clearly defined roles really helped make the process more smooth."
	Desire for more education in the future (5)	RN: "Continue to push education for staff"
	Being educated on MH and/or SOP was valuable (3)	Tech: "Learning to recognizing [sic] the MH symptoms & treatment."
Positive reflections on participants' own learning/performance (11)	Good communication (6)	Participant: "As sim went on, we had better closed-loop communication"
	Successful troubleshooting of unfamiliar supplies/equipment (5)	Participant: "Didn't know how to reconstitute, but figured it out"
Challenges experienced during simulation (8)	Factors that impeded completion of the simulation (7)	Participant: "Ice took a while to get"
	Communication was difficult (1)	Participant: "Couldn't hear everything" [in reference to being the recorder]
Suggestions for improvement of educational activity (21)	Desire for more preparation prior to simulation (11)	RN: "There was some fumbling around looking for things (like insulin). Might be helpful to review what we will need before the sim to help build confidence in everyone for their roles."
	Suggestion to improve materials for education/simulation (4)	Participant: "Put calls in order - MHAUS on bottom"
	Desire for more realism (3)	Tech: "Would have ran actual code in hallway"
	Suggestion for less people delivering education (2)	RN: "Less talking outside of learning experience"
	Desire for interaction with code team (1)	RN: "Interaction with code team"
Suggestions for improvement of SOP (19)	Inadequate supplies/equipment (9)	Participant: "Didn't have access to insulin syringes" Participant: "Had a hard time reading weight-based dosing. Highlighting every other line would help."
	Desire for role cards to be available in NORA areas (3)	Participant: "Want role cards for NORA, liked cards even wanted before MH cart"
	Inadequate staffing (3)	Participant: "After hours staffing is an issue. Might be no nurses."
	Desire for elevator key (3)	Participant: "Elevator key for MH cart."
	Inadequate access to OR (1)	Participant: "Not all have access into the OR for MH cart"
Percieved stress of high-fidelity simulation (3)	Items that contributed to stress during simulation (3)	Participant: "Felt like it took 20 minutes but only took 4"

Appendix I

Process Changes as a Result of the Simulation

Problem Identified	Solution
Unclear if dantrolene (Ryanodex) could be brought to NORA areas in <10 minutes.	Dantrolene was brought to bedside via the MH cart in <10 minutes to all NORA sites in all high-fidelity in situ simulations. Thus, a single, centralized MH cart was decided to be appropriate for this facility.
Staff expressed wish for MH role cards to be available for NORA sites in the case of an MH crisis.	Role cards were hung in proximity to the MH crisis poster in NORA units.
Dantrolene (Ryanodex) weight-based dosing guidelines in MH cart binder were difficult to read, which impeded the safe and timely administration of dantrolene (Ryanodex).	Alternating row highlights on the dantrolene (Ryanodex) weight-based dosing guidelines were added for ease of readability.
No insulin syringes located on MH cart. This obstacle was found to delay the treatment of a simulated life-threatening hyperkalemia.	Insulin syringes were added to simulated and actual MH carts. This was also reflected in the institutions SOP surrounding required MH cart contents.
Limited staffing in NORA areas was recognized. In addition, not all NORA areas employ staff who can administer medications.	The SOP was amended to encourage calling a code overhead in the event of an MH crisis.