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Delayed Emergence From Anesthesia: A Simulation Case for Anesthesia Learners

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Abstract

Introduction: Delayed emergence is failure to regain consciousness following general anesthesia. It commonly involves altered mental status and respiratory compromise leading to increased morbidity, operating room delays, and increased cost. Causes include residual anesthetics, pharmacologic actions, surgical complications, neurologic events, endocrine disturbances, and patient-related factors. Pseudocholinesterase deficiency is an important consideration in delayed emergence. These patients are unable to effectively metabolize the muscle relaxants succinylcholine and mivacurium, leading to prolonged paralysis following administration. **Methods:** This simulation exercise is designed for medical students, student nurse anesthetists, and resident physicians. It is a 1-hour small-group learning activity centered upon a single patient encounter. We employ this exercise using an anesthesiology resident physician to proctor, a simulation technician to program and run, and a faculty anesthesiologist to mentor each session. It is intended to reinforce required reading assignments and improve the approach to delayed emergence from anesthesia. The debriefing includes discussion of risk-reduction strategies for incorporation in clinical practice. This exercise is easily reproduced using modern simulation mannequins without specialized programming. **Results:** Learners provided evaluations of their experience participating in the exercise, and resident physicians evaluated their experience proctoring the sessions. Responses were positive, and constructive criticism led to modifications to the exercise after development. **Discussion:** We use this exercise as an educational opportunity for medical students rotating clinically in our department. Medical students are paired with resident physicians for scenario development and work with faculty to produce valuable educational activities that benefit the entire department.

Keywords

Anesthesiology, Postoperative Complications, Residual Neuromuscular Blockade, Delayed Emergence From Anesthesia, Pseudocholinesterase Deficiency

Appendices

A. Simulation Case.docx
B. Simulation Patient HP.docx
C. Anesthesia Record.docx
D. Lab Results.docx
E. Head CT Report.docx
F. Critical Action Checklist .docx
G. Delayed Emergence Didactic.pptx

All appendices are peer reviewed as integral parts of the Original Publication.

Educational Objectives

At the end of this exercise, the learner will be able to:

1. Identify the occurrence of delayed emergence following general anesthesia.
2. Identify the need for continued respiratory support and mechanical ventilation in a patient failing to emerge from general anesthesia.
3. Develop a differential diagnosis for delayed emergence with attention to reversible causes.
4. Identify patient-, surgical-, and anesthetic-associated risk factors for delayed emergence.
5. Correctly identify pharmacologic agents and dosing for reversing neuromuscular blockade, benzodiazepine, and opioid overdose.
6. Correctly identify onset and recovery from neuromuscular blockade following administration of paralytic agents.
7. Correctly identify and employ respiratory support and pharmacologic therapy for pseudocholinesterase-deficient patients experiencing delayed emergence from general anesthesia.

Introduction

Studies indicate that postoperative complications occur at a rate nearing 25%.[1,2] Postoperative complications occur at significantly higher rates among patients undergoing general anesthesia and having orthopedic and abdominal procedures. Certain procedures are associated with unique additional risks and complications requiring timely intervention in order to reduce negative sequelae.[3-5] A study of in-hospital medical injuries in the United States, of which postoperative complications are a subset, estimated that these complications contribute to 2.4 million extra days of hospitalization, $9.3 billion in added expense, and more than 32,000 deaths annually.[6] Delayed emergence is defined as the failure to regain consciousness 30-60 minutes after general anesthesia, and the clinical presentation often involves both altered mental status and respiratory complications.[7] The paucity of clinical studies on this phenomenon has limited anesthesiologists from defining its true incidence, but one study in New Zealand involving more than 13,000 surgical patients found that prolonged sedation events occurred in the studied center at a rate of about 0.25%, indicating that anesthesiologists are faced with this clinical dilemma once per 400 patients.[2,7-9] The most common causes of delayed emergence are residual anesthetic agents, drug interactions, and polypharmacy therapy.[9] The differential diagnosis for delayed emergence also includes surgical complications, neurologic sequelae, endocrine disturbance, metabolic derangement, and psychiatric conditions.[2,7-9] An organized approach to delayed emergence in the form of development of a differential diagnosis and response to symptoms is imperative for anesthesia providers. Given the difficulty estimating the true incidence and the multiple etiologies of delayed emergence, prior preparation and vigilance are vital and potentially lifesaving when these situations arise.

Pseudocholinesterase (PChE) is a plasma protein synthesized by the liver that has an enzymatic activity of ester hydrolysis, which is important in the metabolism of a number of commonly used medications.[10-12] Biologically active esters requiring PChE for metabolism include the depolarizing neuromuscular blocking agent succinylcholine and the nondepolarizing neuromuscular blocking agent mivacurium. PChE deficiency is a rare but potentially critical cause of postoperative morbidity, manifesting as unexpected, prolonged paralysis, apnea, and delayed emergence following general anesthesia.[11] Unrecognized PChE deficiency can lead to a patient emerging from anesthesia paralyzed but awake following surgery. The clinical combination of delayed emergence and failure to recover from neuromuscular blockade should prompt an anesthesia provider to consider PChE deficiency and institute immediate intervention. It is vitally important that anesthesia providers understand and consider PChE deficiency in their approach to a patient experiencing delayed emergence.

PChE deficiency can be due to multiple etiologies, which are broadly defined as congenital versus acquired. Congenital PChE deficiency is inherited in an autosomal recessive fashion and can be diagnosed and classified using the dibucaine number (dibucaine is a local anesthetic that inhibits normal plasma PChE and has been used as an indicator of abnormalities in PChE activity). Higher values represent normal PChE activity, whereas numbers below 20 represent a lack of PChE activity. The prevalence of PChE deficiency is estimated to be 1:3,000 to 1:10,000 for homozygotes and up to 1:25 for heterozygotes.[10] Acquired causes of PChE deficiency include chronic liver disease, malnutrition, pregnancy, and malignancy and are hypothesized to be due to reduced levels of circulating enzyme.[11] Cholinesterase inhibitors, pancuronium, oral contraceptives, metoclopramide, esmolol, phenelzine, echothiophate eye drops, organophosphate insecticides, and cyclophosphamide are drugs that have been shown to attenuate PChE activity.[11,12]

This simulation exercise is designed for medical students, student nurse anesthetists, and resident physicians rotating clinically in anesthesiology. It is intended to reinforce understanding of required reading assignments and improve learners' approach to delayed emergence events. Initial response to the clinical scenario is intended to highlight understanding of the importance of airway management, development of a differential diagnosis, and team communication. The debriefing includes discussion of risk-reduction strategies for incorporation in clinical practice. In the past 12 months, this scenario has been used and reviewed by four separate groups of rotating medical students from two different medical schools. Medical students rotate in our department for a period of 1 month. During that rotation, they have two simulation lab experiences. The first is an airway management lecture with demonstration and skills lab practice. The second is a simulation scenario exercise proctored by a resident physician and mentored by a staff anesthesiologist. The simulation scenario is designed to highlight important topics relevant to the specialty in a safe environment that closely resembles significant clinical events. The average learner group size in the past 12 months has been three. This simulation exercise can easily be employed by departments that offer clinical rotation to student nurse anesthetists. Our institution is currently working toward further development of our relationship with the nurse anesthesia program so that this can be added to their curriculum.

The purpose of this small-group simulation activity is to supplement required reading assignments with a clinical scenario that encourages learners to synthesize their knowledge into a well-organized approach to intervention and treatment of a potentially life-threatening situation seen in clinical practice. This is a group learning simulation exercise designed to reinforce learners' understanding of delayed emergence from anesthesia and further develop their ability to generate a differential diagnosis and treatment plan when faced with this occurrence. This exercise covers the competency domains of patient care, medical knowledge, and interpersonal and communication skills.

The exercise is designed to be delivered as a 1-hour small-group simulation for learners who have had some exposure to the practice of anesthesiology. We designed the exercise to be delivered to medical students toward the end of a 1-month clinical rotation in anesthesiology. The learners are expected to have completed basic reading assignments from *Morgan & Mikhail's Clinical Anesthesiology,* fifth edition; specifically, the exercise reinforces the information presented in chapters 11 (Neuromuscular Blocking Agents), 12 (Cholinesterase Inhibitors & Other Pharmacologic Antagonists to Neuromuscular Blocking Agents), and 54 (Anesthetic Complications).[12]

This is a highly versatile simulation exercise based upon the presentation of a major diagnostic dilemma commonly encountered in the practice of anesthesiology. The exercise is intentionally written so that it can be adapted to any of the major postoperative causes of delayed emergence with great ease and is not limited to PChE deficiency. With minor modifications to the physical examination and vital signs, the simulation exercise can be altered to highlight opioid or benzodiazepine overdose as well as the additive effects of both agents in a single patient. With modifications to physical exam and test results, the exercise can be altered to highlight endocrine disturbances or neurologic events that would result in delayed emergence. We encourage any user of this material to alter the scenario and use the material for multiple applications.

Methods

This simulation case (Appendix A) focuses on a single patient encounter that occurs in the operating room (OR) at the end of a surgical procedure performed under general anesthesia. The patient is an adult male with a history of obesity, diabetes mellitus, hypertension, and a sedentary lifestyle who is undergoing the surgical excision of a chronically infected pilonidal cyst under general anesthesia in the prone position. The patient has multiple risk factors to consider when the provider is faced with delayed emergence at the end of the operation.

The team should initially recognize the failure to emerge from anesthesia at the end of the procedure and continue supportive measures. The team should verify that all volatile anesthetic agents have been discontinued and continue mechanical ventilation with 100% oxygen using high fresh gas flow rates to maximize elimination of residual volatile agents and prevent diffusion hypoxemia. The team should also closely monitor vital signs for indications of hemodynamic instability.

The next series of critical team actions focuses on generation of a differential diagnosis with attention paid to reversible causes. The team should conduct a targeted physical examination and testing to determine the cause of the delayed emergence. Checking pupil size and light reactivity can give clues to the potential causes of neurologic events and opioid overdose. Monitoring patient temperature is important as hypothermia contributes to delayed emergence. Analysis of end-tidal carbon dioxide levels can indicate the possibility of hyperventilation or hypoventilation as a cause of delayed emergence. Reviewing the anesthetic record and hospital medication record can give clues to potential medication overdosing, drug interactions, and polypharmacy issues that would delay emergence. Ordering serum electrolytes gives an indication of metabolic derangements including serum glucose disturbances that could contribute to delayed emergence. Central nervous system (CNS) imaging could be considered to evaluate for stroke. Finally, using a peripheral nerve stimulator to evaluate for recovery from neuromuscular blockade reveals residual paralysis, which should direct the team to consider PChE deficiency as a cause of this delayed emergence.

Therapeutic interventions to be considered and/or implemented by the team include continued mechanical ventilation support with attention paid to avoid hyper- and hypoventilation, naloxone for the reversal of opioid overdose, flumazenil for the reversal of benzodiazepine overdose, and, following the diagnosis of PChE deficiency, institution of sedation and supportive care for the duration of time required for clearance of the residual neuromuscular blockade.

Initial Scenario Conditions

Initiating event: The actor playing the student provider initiates the exercise by calling the participants to the OR to assist with a problem. The patient does not emerge from general anesthesia following the end of the planned procedure, and the actor requests help.

Circumstances: The patient has a past medical history significant for hypertension, non-insulin-dependent diabetes mellitus, gastroesophageal reflux disease, and recurrent pilonidal cyst. He underwent an elective excision of a chronically infected pilonidal cyst under general anesthesia in the prone position. The induction was uneventful, the surgery was conducted without incident with an operative time of 40 minutes, and the patient was returned to supine position in the gurney prior to discontinuation of the anesthetic. The patient does not emerge from general anesthesia, develops moderate hypertension and tachycardia, and remains apneic and motionless.

Associated symptoms: The patient remains unresponsive to verbal and physical stimuli despite the discontinuation of the general anesthetic. As time progresses, the hypertension and tachycardia worsen, but the patient displays no spontaneous movement and remains apneic. Pupils are normal and bilaterally reactive to light and accommodation if checked. Peripheral nerve stimulation reveals zero response to tetany, train-of-four, and posttetanic train-of-four. This is consistent with residual neuromuscular blockade. Laboratory evaluation is normal; specifically, electrolytes and glucose values remain within normal limits. CNS imaging is normal if it is ordered by the team.

Equipment and Environment

This simulation activity should be performed in a simulation room set up as a mock operating suite. Ideally, the simulation room should have an anesthesia machine complete with mechanical ventilation and all standard American Society of Anesthesiologists monitors. In our facility, this exercise is carried out in a simulation room that has been converted to a mock operating suite. The model, bed, monitors, and equipment are arranged in similar fashion to our real operating suites, while the programming and monitoring of the scenario are accomplished via video feed and remote control. This scenario is simple enough that remote control and video are not required for successful implementation.

This scenario is easily reproduced on modern simulation mannequins without specialized programming of any kind. The patient's vital signs are displayed and remain within normal limits, with the exception of the heart rate and blood pressure, which must be adjusted during the simulation exercise and its branch points. No other specialized programming is required. In our institution, we use the Laerdal SimMan 3G simulation model with Philips monitor for this exercise.

The simulation model should be positioned supine on a gurney similar to those used at the local facility. The model should be dressed in a hospital gown and lying on the gurney covered in a hospital sheet and blanket, as is customary in the facility recovery room. The patient should have a single peripheral IV with either Lactated Ringer's or PlasmaLyte infusing at roughly 200 mL/hour. The patient should be connected to ECG, pulse oximetry, temperature, and noninvasive blood pressure monitors. The patient should have an endotracheal tube in place with mechanical ventilation via connection to the anesthesia machine ventilator, and ventilation settings and vital signs should be displayed on the machine monitor. A light source must be available for checking the pupillary light reflex. A peripheral nerve stimulator should be available for testing recovery from neuromuscular blockade.

Personnel

This simulation learning exercise is extremely flexible depending upon the number of participants. The case can be implemented using a single participant, a single actor, and a facilitator/operator. Roles for the simulation activity can be adjusted to accurately reflect the OR staffing model in the local facility, and involvement of OR nursing staff can add to the realism and value of this exercise as a multidisciplinary team-building activity. Roles in the activity can be played by faculty physicians, resident physicians, certified registered nurse anesthetist staff, nursing staff, or medical students. The number of participants can be increased without detriment to the exercise.

The single actor for this exercise plays the role of student anesthesia provider. That actor starts the exercise by calling the participants to the OR for help with a patient who does not wake up at the end of a procedure. This actor also provides the team with the data and information that they request during the scenario, including the patient's history (Appendix B), anesthetic record (Appendix C), laboratory values (Appendix D), and head CT report (Appendix E), as well as assisting the team as directed during the exercise.

Our institution hosts between two and six medical students per month. We have found the exercise to be more valuable with multiple participants than with single learners. The ideal number of learners for this exercise is three or four in our experience.

Assessment

This simulation case is designed as a learning activity for students rotating clinically in anesthesiology. With that design in mind, the participant assessment was developed based upon team achievement of all critical actions during the exercise. A dichotomous checklist of critical simulation exercise actions (Appendix F) is provided to aid the facilitator in the evaluation process. Failure by the team to achieve any of the critical actions in the exercise should prompt focus on those areas in the debriefing process.

Debriefing

The debriefing for this scenario includes a recap of the main causes of delayed emergence from general anesthesia and their treatment. The discussion covers patient-, surgical-, and anesthetic-related factors increasing the risk of delayed emergence from general anesthesia. The discussion concludes with the relation of these topics to the patient in the scenario in an effort to link the newly acquired knowledge to improved patient care in the future. Facilitators should consider including some of the following elements:

- Open-ended questions by facilitator: The facilitator can begin the session with a question to the primary participant about how he or she feels the scenario went. This often leads to extensive participant-led discussion touching on many of the major issues in the case. The facilitator can also invite any secondary participants and/or observers to comment constructively about the case.
- Brief didactic review: The facilitator should review the assessment tool checklist to identify any critical actions missed by the team so that knowledge and action gaps are addressed in the debriefing. A PowerPoint presentation (Appendix G) that presents in didactic format the relevant knowledge, background information, and explanation of critical actions involved with this case is provided. The facilitator can adapt this presentation to fit the needs of the participants.
- Formal participant evaluation: We do not use this case for formal evaluations, and we have no standardized form or format for such feedback.

Scenario Critical Action Points

Changes in patient condition: The participants should remain in constant attendance on this patient throughout the exercise. No portion of this exercise is conducive to remote management of the patient.

Review of medication documentation: The actor in this exercise produces a printed copy the history and physical upon request from the participants. The actor can also produce the anesthetic record for the team to review.

Differential diagnosis: Participants should develop a differential diagnosis for delayed emergence so that they can formulate a plan for intervention and treatment. This differential diagnosis should include residual volatile anesthetic, opioid overdose, benzodiazepine overdose, residual neuromuscular blockade, electrolyte abnormalities, hyperventilation/hypoventilation, and CNS event as potential causes of the patient's failure to emerge, and participants should work to identify the mechanisms involved with the patient. The team should consider ordering laboratory work to evaluate for metabolic abnormalities. When lab work is ordered, the actor provides the learners with a written copy of the laboratory values. The team should also consider ordering a head CT scan to evaluate neurologic injury. Even though this is not the preferred management, if the team orders a head CT scan, the written report can be provided by the actor in this scenario.

Support of ventilation: Participants should recognize the patient's need for continued respiratory support. Participants should maintain endotracheal intubation and mechanical ventilation given the patient's apnea. Mechanical ventilation should be continued with 100% oxygen at high fresh gas flow rates to improve the clearance of any residual volatile anesthetic agents and prevent diffusion hypoxemia.

Evaluation of patient: The team should verify normal end-tidal carbon dioxide levels to evaluate for hyperventilation/hypoventilation. Participants should verify that there is no residual volatile anesthetic remaining in the patient. They should evaluate core temperature to rule out hypothermia as a potential cause. The team should conduct a physical exam that includes pupillary size and light reflex to evaluate for potential opioid overdose. Presented with this clinical scenario, the participants should consider ordering serum electrolytes to rule out disturbances that could alter mental status such as glucose derangements. The team should confirm with the surgical team total dose of any medications used on the surgical field. Testing of muscle function with a peripheral nerve stimulator should be conducted by the team in order to evaluate for residual neuromuscular blockade. In this scenario, the lack of response to peripheral nerve stimulation is pathognomonic for PChE deficiency. CNS imaging could be considered to evaluate for stroke.

Administration of medication:

- Naloxone: The participants should include opioid overdose in their differential diagnosis. The patient is apneic, and his pupils are normal and reactive. A dose of naloxone is not the preferred intervention and would be considered a management error in this scenario; however, the team should consider naloxone among their interventions. If given, it does not improve the patient's level of consciousness or apnea. Naloxone in this exercise should be dosed via IV, and 0.04-0.08 mg would be the appropriate dose to consider.
- Flumazenil: The participants should include benzodiazepine overdose in their differential diagnosis. A dose of flumazenil is not the preferred intervention and would be considered a management error in this scenario; however, the team should consider flumazenil among their interventions. If given, it does not improve the patient's level of consciousness or apnea. Flumazenil in this exercise should be dosed via IV, and 0.2 mg would be the appropriate dose to consider.
- Propofol: Once the team members have reached the diagnosis of PChE deficiency, they should identify the need to implement sedation until the patient spontaneously recovers from the prolonged neuromuscular blockade. Propofol is the preferred sedative agent in this scenario, and an IV infusion of propofol at a dose of between 50-75 mcg/Kg/min is appropriate.

Nonrecommended actions:

- Neither removing the endotracheal tube nor discontinuing mechanical ventilation is a preferred intervention. The patient is unresponsive, unconscious, and apneic. He does not meet any tracheal extubation criteria; therefore, endotracheal intubation and mechanical ventilation are indicated while the team works to identify and treat the problem.

- Ordering imaging studies prior to checking for recovery from neuromuscular blockade is not a preferred intervention and would be considered a management error in this scenario. A head CT scan should be considered when developing the differential diagnosis; however, prioritizing reversible causes of delayed emergence is indicated prior to imaging studies. If the team orders a head CT scan, they must organize the logistics of patient transport to and from the CT scanner. After arranging these logistics, they are given a written report of a normal head CT scan.
- Delaying sedation therapy once the diagnosis has been made is also not recommended. In this case, it is possible for the patient to be paralyzed but awake following the end of the procedure. Once the team has identified residual neuromuscular blockade as the cause of delayed emergence, it is appropriate to institute sedation until the paralysis is resolved.

Scenario flow: This scenario should flow relatively quickly after the team develops a comprehensive differential diagnosis.

Key aspects of case: The key aspects of this simulation case are the recognition of delayed emergence from anesthesia, the need for continued mechanical ventilation, the identification of residual neuromuscular blockade, and the requirement for supportive care until the resolution of the paralysis. It is also important, once the team recognizes residual neuromuscular blockade as the cause of delayed emergence, that the team members comfort the patient while preparing to administer sedation. This comforting should be in the form of reassuring statements to the patient that the team recognizes what is transpiring and is properly caring for the patient.

This case can easily be presented without formal actors and by using other participants to serve as the nursing staff or other collaborating physicians. The actor playing the role of the student anesthesia provider should be briefed about the critical actions and anticipated flow of the case ahead of time. After the learners have reached the diagnosis of PChE deficiency and intervened, disposition of the patient should be addressed. If the team does not suggest it, the actor can offer to take the patient to the recovery area where he can remain on sedation and mechanical ventilation until the paralysis resolves so that the OR can be turned over for the next scheduled procedure.

Results

This simulation case has been offered on multiple occasions in our institution. It has been delivered using an anesthesiology resident physician to proctor and debrief, a simulation technician to program and run the exercise, and a faculty anesthesiologist to mentor each session. We have used this simulation case as an educational opportunity for medical students rotating clinically in our department; however, we have had the opportunity to run it with resident physicians as well. Simulation runs have had no difficulty adhering to the described protocol.

Group performances during the simulation are monitored in real time by the proctor using the critical action checklist as a guide for completion of the objectives. In our experience with this module, participants think out loud, propose explanations for the changed patient condition, suggest interventions, and then implement therapeutic intervention after group agreement.

Learners begin with manual ventilation using the anesthesia circuit connected to the endotracheal tube and look for an end-tidal carbon dioxide waveform along with respiratory rate and vital signs on the monitor. Once they have elucidated that the anesthetic has been discontinued and that the patient is apneic, they begin to create a differential diagnosis, and the scenario starts to flow quickly. Initially, the focus is placed on ruling out sedatives such as benzodiazepines and opioids as causative agents. With normal pupillary size in combination with reasonable total doses of opioid and benzodiazepine during the case, oversedation is usually thought unlikely; however, groups sometimes attempt pharmacologic intervention in the face of this evidence. Malignant hyperthermia has been explored in their differential diagnoses but thought to be unlikely due to the lack of rigidity, hypercapnia, and hyperthermia. A train-of-four, when checked, elucidates the lack of twitch return. Upon the realization that this is abnormal, the anesthetic record is reviewed to determine that succinylcholine was the neuromuscular blocker used during the case, and the learners realize this scenario is likely caused by an abnormal response to succinylcholine. While the learners work through the differential diagnoses, the patient becomes increasingly tachycardic and hypertensive, raising the sense of urgency to initiate management. This process is markedly more rapid and organized when running the simulation session with resident physicians as they more rapidly advance to testing neuromuscular function than do groups made up of medical students only. It is important to note that the development of the differential diagnosis and investigation into reversible causes do not occur in a stepwise manner for each group and that examination and testing can occur in any order along the continuum. For groups that test neuromuscular function first, this exercise is completed very quickly, whereas groups that focus on residual volatile agent and oversedation take additional time to determine the cause of the delayed emergence.

Once they understand what is causing the delayed emergence, all groups that reach the correct diagnosis elect to administer sedation, which quickly resolves the patient's tachycardia and hypertension. The learners should elect to transport the patient to the postanesthesia care unit and support the patient with continued mechanical ventilation with normal ventilator settings and oxygen concentration; the actor can offer this suggestion if the team stalls after implementing sedation. A plan should be formulated to continue checking a train-of-four until adequate reversal is established and to attempt emergence at that time.

Learners are not officially evaluated on their performance during this simulation exercise, and this is intentional. Our department uses these simulation exercises in order to augment the instruction learners receive during clinical care of patients in the OR. It is our desire to provide an environment of active learning that gives learners an opportunity to work closely with resident and attending physicians in an environment free of performance expectations so that they are more apt to surrender to the simulation learning environment in a positive manner.

Review of critical action checklists from this simulation exercise demonstrates that the vast majority of groups reach the correct diagnosis in a timely fashion. One group during the past 12 months advanced to ordering a head CT scan before checking for residual neuromuscular blockade, and in debriefing, that team's members stated that because the scenario started at the end of the surgical procedure, they did not think the patient was paralyzed. Groups have elected to give flumazenil for presumed sedative overdose in this scenario, and in debriefing, those teams explained that a lack of definitive physical exam findings that would exclude benzodiazepine overdose led them to this decision. After the initial submission of this exercise for publication, editorial staff identified shortcomings in the critical action checklist if the exercise were to be delivered by a nonanesthesiologist. As a result of those suggestions, the critical action checklist was revised to more accurately reflect the flow of the exercise.

Learners are asked to comment and rate the simulation exercise experiences on their official evaluation of the clinical rotation within our department using an electronic program evaluation system. The simulation session is evaluated using a seven-question evaluation form within our electronic program management software in a similar fashion to didactic lectures. Overall evaluations of both the simulation session and the instructing staff are rated on a 5-point scale (1 = *poor,* 5 = *excellent*). In the past 12 months, this simulation session has received an average rating of 4.75, and the staff has gotten an average rating of 5. Unedited comments from medical students include the following:

- "Very relevant. Felt one-on-one in terms of teaching."
- "It was explained in a very thorough way, which made it way more useful in terms of understanding what was actually going on."
- "I liked the thoroughness and time spent."
- "Nothing is better than a real patient, but you can't change that."

Resident physician feedback is also obtained and taken into consideration. After each simulation session, the resident facilitator and the attending mentor debrief the experience. These individuals discuss the session, suggesting edits and improvements that can be made to the exercise as well as ideas for the future. Specifically related to this exercise, resident physicians agreed with learners about providing an anesthesia record for them to refer to. Resident physicians also identified early on that medical students were not facile with the use of the nerve stimulator, and as a result, they now dedicate time in the OR clinical environment to teaching the rotating students how to perform train-of-four testing and how to interpret the results. Additionally, resident physicians commented that proctoring these simulation exercises has made them more organized in their approach to patient care in the OR, especially in the face of atypical situations. They find these simulation exercises beneficial and want to continue offering them.

Discussion

Our department typically has three simulation session projects under development at any one time, with the understanding that each one takes approximately 18-20 months to develop from draft to completion. Each simulation exercise that we develop undergoes careful consideration for its value to the profession and potential for positive impact upon learners prior to submission for peer-reviewed publication. Three primary objectives motivate the research, development, and implementation of these simulation exercises within our institution.

First, we wish to foster and promote cooperative scholarship, education, and teaching between our clinical department and the school of medicine. Medical students at our institution are not required to rotate clinically in anesthesiology, which limits the exposure these students have to our specialty. The research and development of these exercises have opened an entirely new academic bridge between the school of medicine and our clinical department. We begin with an idea and an interested medical student who volunteers for the project. We pair that medical student with a resident physician and faculty member within our residency training program to form a team that accepts responsibility for the completion of the project. In this manner, we are able to instruct and mentor our medical students and resident physicians through the literature search process. As the projects are developed, medical students, resident physicians, and our faculty further develop their abilities in the scientific writing process. As these exercises are submitted for peer-reviewed publication, our medical students, resident physicians, and faculty become more facile with the process of scientific literature publication and ultimately gain recognition for their effort.

Second, these exercises have been implemented as a means to augment the clinical experience that medical students receive when rotating electively within our department, to expand upon the conventional teaching methods that have been historically employed, and to foster an environment of active learning. Reviews of the elective rotation in our department identified medical students' desire for expansion of active learning opportunities in the form of both skills labs and hands-on instruction in the technical aspects of our specialty. These sessions allow inexperienced learners to practice their approach to clinical anesthesia care in an environment free of time constraints and external pressures, which can be especially intimidating in the OR environment. Medical student reviews of the anesthesiology rotation conducted using our electronic program evaluation system indicated that external pressures in the OR environment caused performance anxiety the students felt was detrimental to the improvement of their clinical skills. Students indicated that the simulation sessions offered an environment of learning free from those pressures such that they could practice and develop necessary skills without feeling distressed or rushed by the harried pace of the OR. Students also especially enjoyed dedicated time with anesthesiology residents and staff outside of the OR when they could ask questions, seek advice, and gain perspective on clinical care dilemmas occurring in the OR.

Third, we develop and implement these exercises as a method of academic career development for our resident physicians and junior faculty. Each month, one of our resident physicians chooses one of our simulation exercises to present to the rotating medical students. The resident physicians work with a faculty member to prepare and present the simulation exercise. In this manner, our resident physicians have the opportunity to develop their teaching skills with faculty mentorship and are given the opportunity and responsibility for formal teaching. The resident physician receives feedback in the form of medical student comments on the rotation evaluation as well as direct feedback from the faculty mentor. This also benefits our faculty in the areas of academic development and mentorship skill improvement.

Overall, the addition of this simulation case to our didactic exercises has been quite positive. Participants related that the simulation exercise was challenging, appropriate to their level of training, and relevant to clinical rotation in our department. Most participants felt that they performed well in their assessment and therapeutic interventions but admitted that they had never encountered an actual case of PChE deficiency.

Learners who participate in this scenario have differing levels of clinical knowledge concerning delayed emergence, and it can prove more difficult for inexperienced students to reach the diagnosis of PChE deficiency. This exercise is designed to emphasize the approach one would take towards a patient with delayed emergence regardless of the diagnosis reached; it also stresses that sedation with supportive mechanical ventilation is key when prolonged neuromuscular blockade is present. Participants provided positive feedback about their learning experience through the clinical scenario and expressed a greater understanding of anesthetic emergence, in addition to discovering the common reasons for delayed emergence. We believe this exercise has been successful in achieving its objectives.

Improvements that can be made to the simulation case include inclusion of an anesthesia machine for a more realistic feel to the OR setting. Additionally, allowing the pulse oximeter to have an active constant pitch volume, with active alarms for when the patient's vital signs and end-tidal carbon dioxide levels reach alarm thresholds, is key to adding a greater sense of urgency to the situation. Variations in end-tidal carbon dioxide based on the adequacy of ventilation also add a greater complexity to the scenario and expand the differential diagnosis. Alterations in end-tidal carbon dioxide can lead to sedation as well, thus placing more emphasis on appropriate ventilation of the patient in the management plan while ruling out other causes of delayed emergence. For advanced learners who are likely to arrive at the correct diagnosis in rapid fashion, the exercise can be further modified to include a discussion about disclosing the diagnosis to the patient and developing a plan for testing the family for PChE deficiency.

This simulation was designed to be extremely flexible depending on the size of the participant group and has worked well for us with groups as small as two medical students. It can also easily be modified to address any of the major causes of delayed emergence so that this one session can be used multiple times without repeating the exact diagnostic dilemma. We have not used this case for opioid or benzodiazepine overdose as those subjects are addressed at multiple other points in the curriculum; however, this case would be quite easy to adjust for any group wishing to use it for those diagnostic dilemmas. We are currently revising our blood glucose management protocol and plan to use this simulation case to highlight intraoperative hypoglycemia as a cause of delayed emergence to reinforce the importance of vigilant glucose monitoring with insulin therapy in the OR.

We believe this simulation case is a useful tool to aid in the training and experience that students have when rotating clinically in our department. We have implemented the exercise in regular rotation with students in our department with positive results. There are no major pitfalls with the scenario as any combination of missed diagnosis or improper actions taken leads to an important learning point in management of delayed emergence. Regardless of whether a train-of-four is elicited first and prolonged muscle relaxation is suspected, institution of management and ruling out all other causes still become important. Whether it takes 5 minutes or 30 minutes to complete the scenario, all participants will be able to benefit and learn from the approach and management of delayed emergence.

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