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Acute Hypoxemia in Infants With Cyanotic Complex Cardiac Anatomy: Simulation Cases for Pediatric Fellows

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Abstract

Introduction: Cardiopulmonary compromises are infrequent but high-acuity events that occur at pediatric hospitals. Simulation is a powerful modality to teach fellows in pediatric critical care, cardiology, and neonatology important clinical skills in managing complex cardiorespiratory pathophysiology in infants with cyanotic heart disease. **Methods:** We developed three simulation cases of hypoxemia involving differing complex cardiorespiratory pathophysiology in neonates/infants with cyanotic heart disease. Through teamwork, the participants were expected to recognize hypoxemia, work through a differential diagnosis, and implement the medical intervention needed to temporize while awaiting further procedures. Assessment of the participants' performance was via direct observation during the simulated activity. Debriefing occurred immediately using a formal debriefing framework. **Results:** In 10 years, these three cases have been utilized approximately 48 times. Participants subjectively increased their confidence in managing cardiopulmonary events and improved their teamwork and communication skills in similar high-stress events. **Discussion:** This unique module advanced learners' knowledge by building on their Pediatric Advanced Life Support and Neonatal Resuscitation Program foundation, identified management deficits in the care of patients with complex cardiorespiratory pathophysiology, and taught effective teamwork with role assignment and closed-loop communication.

Keywords

Hypoxemia, Hypoxia, Hypoplastic Left Heart Syndrome, Tetralogy of Fallot, Transposition of Great Vessels, Transposition of Great Arteries

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Appendices

A. Simulation Case 1.docx
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C. Simulation Case 3.docx
D. Chest X-rays.pptx
E. Echocardiogram Reports .pptx
F. iSTAT Values.docx
G. Simulation Ground Rules .docx
H. Debriefing Ground Rules .docx
I. Debriefing Framework.docx
J. Postsimulation Evaluation .docx

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

Educational Objectives

By the end of this module, learners will be able to:

1. Identify the signs and symptoms of cardiorespiratory compromise in neonates/infants with complex cyanotic heart disease.
2. Develop a differential diagnosis for hypoxemia based on the underlying cardiac anatomy.
3. Demonstrate and implement the medical management needed to augment physiology while awaiting emergent surgical or catheter-based interventions.
4. State the additional personnel and equipment needed for this medical emergency and initiate appropriate monitoring techniques.
5. Practice effective teamwork, including leadership roles and responsibilities, resource and workload allocation, closed-loop communication, and situational awareness.

Introduction

Pediatric residents enter fellowship having learned cardiopulmonary resuscitation during Pediatric Advanced Life Support (PALS) and Neonatal Resuscitation Program (NRP) training courses.[1] Through these algorithm-based protocols, they learn skills that are the foundation for resuscitation in the typical pediatric patient population. However, as residents enter fellowship, the pathophysiology of their patients is more complex, and their resuscitative efforts need to expand beyond PALS and NRP.

In a review of the educational literature, no theme-based simulation curriculum was found that focused on high-acuity low-frequency cardiac critical care events for the advanced pediatric trainee (pediatric fellow).

The goal in developing this module was to provide an advanced interprofessional learning experience of a neonate/infant having profound hypoxemia leading to cardiopulmonary compromise. Each case was developed to highlight different cardiovascular pathophysiologies that have the common end point of hypoxemia. Hypoxemia is a very common issue in cardiac critical care. Low oxygen levels in neonates/infants without congenital heart disease are largely due to pulmonary pathophysiology.[2] The stepwise approach to treating hypoxemia in congenital heart disease patients first requires a baseline understanding of their complex cardiac anatomy. This includes knowing the preoperative and postoperative anatomy and physiology. Through the cases, learners are taught to formulate a differential diagnosis for hypoxemia by working through certain questions that help to focus their interventions (both medical and surgical/catheter-based) to the underlying problem(s) causing systemic desaturation. Participants are taught and then practice a shared mental model for hypoxemia. Furthermore, learners practice effective teamwork principles, including identification of a leader, assignment of roles and responsibilities, and closed-loop communications.

The targeted learners are pediatric critical care, cardiology, and neonatology fellows, as well as advanced practice nurses working in pediatric, cardiac, or neonatal intensive care units (ICUs). Prior completion of PALS by all participants is required. These simulations were developed to be performed in situ but can also take place in a simulation center.

Methods

These three cases (Appendices A-C) were developed to offer participants a hands-on learning module for complex cardiorespiratory pathophysiology in neonates/infants with differing cyanotic heart disease leading to hypoxemia. Each simulation scenario was created after real clinical cases highlighted the difficulty advanced pediatric trainees had in approaching the cardiac critical care patient beyond the PALS/NRP algorithms.

We implemented these cases in our curriculum in two ways. First, three simulation sessions per month (weekday day shift, weekday night shift, and weekend day shift) were incorporated into our educational curriculum in the cardiac ICU. These cases were three of over 30 in our library that are rotated during the academic year. Second, we taught these three themed cases over an extended simulation session (3 hours) either during fellows' orientation week or during their weekly educational protected time.

The common mental model for all three cases centered on asking certain questions that helped focus the interventions. Each case first required an understanding of the complex cardiac anatomy particular to each patient—specifically, how a drop of blood flowed in this individual heart. Next, the learner needed to understand how that underlying blood flow had been perturbed and caused profound hypoxemia. Was the blood returning to the left atrium less oxygenated than it should be? Was the blood returning to the right atrium less oxygenated than it should be? Was there a maldistribution of blood flow due to inadequate mixing or decreased pulmonary blood flow?

The first case was a neonate with transposition of the great arteries with profound hypoxemia due to a restrictive atrial communication. Medical management to augment atrial-level mixing was an expected intervention by learners while they awaited the definitive intervention of balloon atrial septostomy. Volume resuscitation and a widely patent ductus arteriosus ensured maximal fill of the pulmonary bed and therefore the left atrium, so as to aid in shunting of the oxygenated blood from the left atrium to the lower-pressure right atrium to improve oxygenation of the blue blood going out to the systemic circulation (right atrium à right ventricle à body). Furthermore, by decreasing oxygen consumption through sedation and paralysis and increasing the concentration of oxygen in the blood by intubation and delivery of 100% FiO_2, the mixed and pulmonary venous saturations increased, respectively, and the overall systemic oxygen level increased as well.

The second case was an infant with unrepaired tetralogy of Fallot whose hypoxemia was due to a hypercyanotic (Tet) spell. There was increased obstruction across the right ventricular outflow tract (RVOT) leading to decreasing pulmonary blood flow. This in turn led to increased right-to-left shunting across the ventricular septal defect (VSD). The RVOT obstruction was made worse by tachycardia. This is often a vicious cycle—agitation, increased heart rate, hypoxemia, body increasing heart rate to respond to low oxygen delivery, the obstruction worsening, and so on. Learners needed to manipulate the physiology to increase oxygen saturations. The systemic oxygen level would increase only as more blood flow was sent to the lungs. Oxygen would increase the pulmonary venous saturation, but the underlying issue was getting blood flow across the RVOT. The volume of blood filling the right venticle needed to be increased. This could be achieved in two ways—by adding to the absolute volume returning to the right ventricle (transiently, with a knee-to-chest maneuver, or more definitively, by volume resuscitation) and by slowing the heart rate and increasing the filling/diastolic time (sedation and/or beta-blocker). Lastly, the systemic vascular resistance could be increased with phenylephrine, which would decrease the right-to-left shunting at the VSD, increase the right ventricle volume, and force more blood across the RVOT. All vital signs would improve as the physiology was properly manipulated to increase the oxygen saturations.

The final case was an infant with hypoplastic left heart syndrome that had undergone the first-stage palliation surgery with a modified Blalock-Taussig shunt. Hypoxemia was due to shunt occlusion causing decreased pulmonary blood flow. Learners needed to medically manage the physiology to increase pulmonary blood flow while awaiting the definitive catheter/surgical procedure. Increasing systemic vascular resistance through volume resuscitation and phenylephrine would push more blood flow through the obstructed shunt and help increase pulmonary blood flow. A heparin bolus could decrease an existing clot or prevent clot propagation (if a clot was present or the shunt was narrowed by torsion), further augmenting pulmonary blood flow. In addition, learners needed to maximize both the mixed and pulmonary venous saturations. By decreasing oxygen consumption through sedation and paralysis and increasing the concentration of oxygen in the blood by intubation and delivery of 100% FiO_2, the mixed and pulmonary venous saturations would increase, respectively, and the overall systemic oxygen level would increase as well.

The facilitators should review the simulation cases prior to the educational activity and have a full understanding of the anatomy and physiology of each congenital lesion. These scenarios are best preformed in situ, so that the environment is familiar to all participants and participants' true roles are maintained. Postsimulation, there should be a designated space to debrief either at the bedside or in a room in close proximity to the ICU.

Equipment

The simulation is designed to occur in a real clinical patient care room with an infant/neonatal high-technology simulator to increase realism and fidelity. The simulator is positioned in the ICU bed/crib with the appropriate setup (monitoring, IV, moulage, medications infusing, etc.) according to each scenario. An ICU bedside cart is in place with personal protective equipment, including gloves and alcohol rub. The environment should be equipped with access to oxygen delivery devices (nasal cannula, face mask), an infant bag valve mask (self- or flow inflating), suction, a fully stocked code cart with mock medications (replica), code sheets, and an emergency medication weight-based book (if utilized) outside of the room. Emergency airway equipment should be readily available with oral/nasopharyngeal airways, laryngoscope handles and blades (size Miller 0 and 1), 3.0 and 3.5 endotracheal tubes cuffed and uncuffed, infant stylets, endotracheal tube securement device, and carbon dioxide sensor (capnography or pH chemical CO_2 detector). The defibrillator should be in the ICU, in the normal location, with appropriately sized defibrillator pads. Ancillary data (chest X-ray, echocardiography report, laboratory values; see Appendices D-F) are available upon participant request.

Personnel

Two personnel are minimally needed to orchestrate each session, including a simulation operator to control the simulator and a trained facilitator who is the subject matter expert. The scenario is programmed and tested (dry run) by the simulation operator prior to the session to ensure standardization/appropriateness of the scenario flow. Occasionally during the session, there is a need for the operator, with facilitator guidance, to override and adjust the parameters on the fly to respond to the participants' actions. If available, a unit nurse educator/clinical expert/leadership nurse is helpful to co-debrief the nursing component of the simulation exercise. The simulation operator is needed to program the scenario ahead of time, set up the mannequin, and control the simulator actions during the session. If necessary, the facilitator supplements information and ancillary data as requested.

Scenario Flow

Prior to the start of the session, the simulation ground rules (Appendix G) are reviewed. At the start of the session, only the bedside nurse is present, and the facilitator reads the introduction of the scenario, including vital signs and pertinent history.

The session takes 55 minutes to perform: 5 minutes to review the ground rules and educate participants about the mannequin, 20 minutes for the scenario, and 30 minutes to debrief.

Assessment and Debrief

The participants are assessed by direct observation of expected interventions and actions, as well as teamwork and use of closed-loop communication during the session. Debriefing is led by the facilitator, occurs immediately after completing the scenario, and begins by discussing the debriefing ground rules (Appendix H). Group and individual performances and participant reflection and self-assessment are then reviewed using the debriefing framework (Appendix I). After a brief introduction, the debriefing framework leads the participants through three phases—reactions, analysis (crisis resource and medical management), and summary. The debriefing begins by exploring the reactions of the participants to the simulated case. After ample exploration in the reaction phase, the debriefer moves into the analysis phase. This phase is divide into two parts. The first section focuses on effective teamwork principles, including leadership roles and responsibilities, communication, resource and workload allocations, and situational awareness. The second section concentrates on the differential diagnosis and medical management of the case. After thorough exploration, the debriefer closes the debriefing session with all participants stating a take-home point/pearl they have learned. Formal written feedback summarizing the objective and learning points for each case, in addition to any specifics particular to that individual session, is sent to all learners. All participants fill out an evaluation immediately after the session is complete (Appendix J).

Results

Since their development in 2010, these simulation cases have been used 48 times with 444 providers (Table 1).

Table 1. Simulation Attendance by Provider Type (*N* = 444)

Professional Designation	No. (%)
Fellows	100 (23%)
Advanced practice nurses	26 (6%)
Nurses	221 (50%)
Respiratory therapists	44 (9%)
Attendings	14 (3%)
Residents	25 (6%)
Certified registered nurse anesthetists	2 (0.5%)
Medical students	2 (0.5%)
Others	10 (2%)

All learners reported that the module achieved the stated learning objectives (Table 2). Ninety-seven percent found the activity to be appropriately challenging. Ninety-eight percent planned to incorporate what they had learned into their practice. All learners reported that subsequent participation in similar real-life clinical cases was less anxiety provoking after simulating such events. They also felt an increased confidence in teamwork and communication after participation.

Table 2. Postsimulation Evaluation Results

Evaluation Statement	M^a	Percentage
The learning objectives of the activity were clear or became evident during the debriefing.	4.832	97%
The equipment and setup helped me achieve the learning objectives.	4.590	92%
The equipment and setting were realistic.	4.587	92%
The scenario (medical story underlying the simulation) was realistic.	4.864	98%
The facilitator used the simulation equipment effectively.	4.829	97%
The discussion of my performance was useful.	4.741	95%
The facilitator was supportive and created a safe learning environment.	4.869	97%
The facilitator enhanced the educational value of the learning experience.	4.880	98%
I found the activity to be appropriately challenging.	4.842	97%
The activity was appropriate for my level of learning.	4.811	96%
I would like to participate in this type of learning again.	4.844	97%
I plan to incorporate what I learned into my practice.	4.901	98%

[a]Scale: 1 = *strongly disagree,* 2 = *disagree,* 3 = *neutral,* 4 = *agree,* 5 = *strongly agree.*

Discussion

To our knowledge, this is the first multicase themed publication in *MedEdPORTAL* focusing on hypoxemia in cyanotic heart disease for pediatric fellows. The incorporation of this resource into our cardiac critical care curriculum helped our learners working in pediatric, cardiac or neonatal ICUs advance their knowledge by building on their PALS/NRP foundation. Through formalized assessment and debriefing, knowledge and management deficits in patients with complex cardiorespiratory pathophysiology could be identified and education performed in a nonthreatening environment.

This three-case themed module is an innovative way to introduce education through simulation into any ICU that cares for complex cardiac patients. Through this module, learners formulate a differential diagnosis for hypoxemia by working through certain questions that help to focus their interventions to the underlying problems causing systemic desaturation. Is the blood returning to the left atrium less oxygenated than it should be? Pulmonary venous desaturation can be due to lung pathophysiology and includes, but is not limited to, pleural effusions, atelectasis, or pneumothorax. These causes can quickly be ruled in or out by a chest X-ray. Furthermore, pulmonary venous saturation can be maximized with intubation and delivery of 100% FiO_2. Is the blood returning to the right atrium less oxygenated than it should be? Mixed venous desaturation can be caused by increased systemic extraction (infection/sepsis, agitation), anemia, or low cardiac output. The mixed venous saturation is optimized with control of fever, sedation with or without paralysis, transfusing packed red blood cells if anemic, and inotropic support in the setting of low output. Lastly, is there a maldistribution of blood flow? Is there inadequate mixing—intracardiac (small atrial communication) and/or extracardiac (restrictive ductus arteriosus)—that needs to be addressed? Is there decreased pulmonary blood flow (shunt occlusion or torsion, outflow tract obstruction, etc.) that can be augmented while awaiting surgical/catheter intervention? Our participants learn to approach hypoxemia in cardiac patients in a stepwise fashion through a taught and practiced shared mental model. This could then be incorporated into their real practice.

Previous studies have shown that formal debriefing improves knowledge acquisition and team leader performance.[3-5] Our debriefing was learner centric, focusing on group and individual performance and team dynamics through the use of reflection on action and self-assessment.

Earlier work has shown that the use of simulated cardiopulmonary arrest events reduces anxiety and improves performance during actual events.[6,7] We found this to be true as well. Our targeted learners all subjectively increased their confidence in managing the common cardiopulmonary event of hypoxemia. In addition, they improved their teamwork and communication skills in comparable high-stress events.

Limitations we found in implementing this learning module in our fellow education curriculum included physical bed space in our busy tertiary care ICU. When this was the case, we often were able to use the treatment room. Another limitation we encountered was maximizing the number of team participants. By scheduling the learning module and thereby not surprising the nursing team, nursing participants were identified beforehand and their real patients covered, allowing more to attend the session. The opposite was true for fellow participation. We found that by surprising fellows with the session, the number of on-service ICU fellows participating increased.

In addition to the above, limitations of this educational module include that our data were self-reported and reflected learners' perceptions, not their actual skills. Future directions will focus on ways to objectively measure how our simulation advances learners' knowledge and impacts patient care.

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Ethical Approval
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References

1. Kleinman ME, Chameides L, Schexnayder SM, et al. Part 14: pediatric advanced life support: 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. *Circulation*. 2010;122(18)(suppl 3):S876-S908. https://doi.org/10.1161/CIRCULATIONAHA.110.971101
2. McMillan JA, DeAngelis CD, Feigin RD, Warshaw JB, eds.*Oski's Pediatrics: Principles and Practice*. 3rd ed. Philadelphia, PA: Lippincott Williams & Wilkins; 1999.
3. Cheng A, Hunt EA, Donoghue A, et al; for EXPRESS Investigators. Examining pediatric resuscitation education using simulation and scripted debriefing: a multicenter randomized trial. *JAMA Pediatr*. 2013;167(6):528-536. https://doi.org/10.1001/jamapediatrics.2013.1389
4. Couloures KG, Allen C. Use of simulation to improve cardiopulmonary resuscitation performance and code team communication for pediatric residents. *MedEdPORTAL*. 2017;13:10555. https://doi.org/10.15766/mep_2374-8265.10555
5. van Schaik SM, Von Kohorn I, O'Sullivan P. Pediatric resident confidence in resuscitation skills relates to mock code experience. *Clin Pediatr (Phila)*. 2008;47(8):777-783. https://doi.org/10.1177/0009922808316992
6. Bishop-Kurylo D, Masiello M. Pediatric resuscitation: development of a mock code program and evaluation tool.*Pediatr Nurs*. 1995;21(4):333-336.
7. Granneman S, Conn VS. An evaluation of the effectiveness of competency-based code blue education.*J Nurs Staff Dev*. 1996;12(6):283-288.

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