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Pediatric Emergency Medicine Didactics and Simulation (PEMDAS) Telesimulation Series: Hyperleukocytosis

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Abstract

Introduction: Hyperleukocytosis, an infrequent presentation of new-onset leukemia, is a medical emergency requiring prompt recognition and treatment. It can include altered mental status, fever, critical electrolyte derangements, and coagulopathies. Due to the COVID-19 pandemic, this simulation was created as a telesimulation in order to adhere to mandatory physical distancing guidelines while addressing learning objectives. **Methods:** This simulation was designed for pediatric emergency medicine fellows and featured a pediatric patient presenting with fever, altered mental status, and respiratory distress. After an initial assessment and appropriate workup, the patient developed tumor lysis syndrome, coagulopathies, and new-onset neurologic changes requiring appropriate interventions. A debriefing guide and participant evaluation form were utilized. **Results:** This telesimulation was implemented at five different institutions, with evaluation surveys completed by 22 pediatric emergency medicine fellows. The scenario was rated on a 5-point Likert scale (1 = *strongly disagree,* 5 = *strongly agree*) and was generally well received, with participants rating the simulation as effective in teaching the recognition ($M = 4.8$) and management ($M = 4.6$) of hyperleukocytosis. Participants felt that virtual telesimulation was effective compared to other distance learning methods ($M = 3.9$). **Discussion:** This simulation-based curriculum allows learners to practice identifying and managing hyperleukocytosis. We found that it was well received in both in-person and virtual formats.

Keywords
Hyperleukocytosis, Simulation, Pediatric Emergency Medicine, Emergency Medicine, Hematology, Oncology, Online/Distance Learning

Educational Objectives

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

1. Demonstrate the initial assessment and stabilization of pediatric patient presenting with hyperleukocytosis.
2. Synthesize the symptoms and diagnostic profile to identify hyperleukocytosis.
3. Communicate and apply emergency management principles, including anticipated or potential complications of hyperleukocytosis such as tumor lysis syndrome–associated electrolyte derangements, coagulopathies, and neurologic risk.
4. Recognize neurologic deterioration with communication of an appropriately updated emergency management plan including risk of stroke.

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Introduction

The purpose of this simulation-based curriculum is to aid pediatric emergency medicine (PEM) fellows in the recognition and management of hyperleukocytosis, an infrequent but high-risk complication of new-onset leukemia. Hyperleukocytosis, defined as a white blood cell (WBC) count greater than 100×10^9/L, is a medical emergency that necessitates prompt recognition and management given the severity of the pulmonary, neurologic, and renal microvascular complications.[1]

While the presentation of leukemia in children is often a nonspecific constellation of symptoms (e.g., fever, fatigue, back/extremity pain, headache), it uncommonly presents with symptoms of leukostasis. The markedly elevated WBC count leads to increased viscosity and concomitant obstruction of the microvasculature, culminating in tissue hypoperfusion.[2,3] The symptoms of leukostasis are related largely to the underlying vascular complications, including occlusion of the vessels, thrombi, and disseminated intravascular coagulation (DIC).[4] While multiple systems are affected, the two most common are the neurologic and pulmonary systems.[5] Patients can present with hypoxia, dyspnea, tachypnea, or respiratory failure. Imaging may demonstrate diffuse, bilateral infiltrates that may or may not correlate with rales on exam. Central nervous system symptoms can include headache, dizziness, vision changes, delirium, lethargy, ataxia, or papilledema. Retinal hemorrhages may be seen on physical exam, and intracranial hemorrhage may be seen on CT. Presentations can also include bowel ischemia, priapism, and myocardial ischemia.[4] The evaluation and management of hyperleukocytosis should start with the standard management of airway, breathing, and circulation, and definitive management consists of decreasing the number of circulating leukoblastic cells via cytoreductive therapy while initiating supportive measures for tumor lysis syndrome (TLS) and management of DIC.[6]

Although hyperleukocytosis is an uncommon presentation of leukemia, the increased early mortality and morbidity associated make it essential that physicians are adept at not only recognizing it but also initiating management. While there is a published simulation for TLS,[7] curricula surrounding the management of hyperleukocytosis are lacking. Although review articles on the topic exist,[5,6] our curriculum employs simulation as a means for learners to engage in experiential learning by participating in concrete experiences followed by reflection. This resource was created as a stand-alone simulation-based curriculum, but it can be used in series as part of a longitudinal curriculum.

This resource was developed for PEM fellows but could be used for pediatric and emergency medicine residents and adapted for use across the spectrum of health care providers. Due to the COVID-19 pandemic, the simulation was created as a telesimulation in order to adhere to mandatory physical distancing guidelines while addressing learning objectives. The definition of telesimulation is evolving but generally refers to a simulation case where at least one participant is remote.[8] All cases for this curriculum were run with all participants physically separated. Simulation curriculum goals can be the same for telesimulation and in-person simulation in spite of the lack of physicality with telesimulation. While we have not run a cost analysis of telesimulation, it theoretically could be less cost intensive compared to in-person simulation with a manikin since telesimulations can be run without an in-person simulation tech and without the cost of a manikin. Thus, telesimulation may be a more accessible modality to use in low-resource settings even without a pandemic, as it requires only a screen-based device and internet connection.

Methods

Development

Designed by PEM physicians and pediatric oncologists with curriculum design and simulation experience, this simulation case (Appendix A) was intended to teach concepts around the recognition and management of hyperleukocytosis to PEM fellows. As the scenario was designed for medical providers in the pediatric emergency department, participants were expected to have prerequisite knowledge about the general approach to the assessment and management of a critically ill child. The case was initially conceptualized to be run in person prior to the COVID-19 pandemic in response to a case of a child with the same disease process. It was subsequently adapted to a telesimulation with an entirely virtual format in order to adhere to mandatory physical distancing guidelines implemented in response to the COVID-19 pandemic. We include a short facilitator preparation section in Appendix A to orient novice telesimulation facilitators to the modality.

Equipment/Environment

The simulation was conducted entirely online with the use of videoconferencing software. All sites utilized Zoom; however, other platforms such as Microsoft Teams or WebEx could be used. Participants were oriented to the Zoom software platform for telesimulation. This platform is similar to the American College of Emergency Physicians (ACEP) TeleSimBox, which utilizes a sim-on-rails modality with a video monitor embedded within the video.[9] ACEP SimBox is a free open-access web-hosted medical simulation platform designed for novice simulation facilitators. Its peer-reviewed simulation cases were adapted via ACEP TeleSimBox during the COVID-19 pandemic to be completely remote and include telesimulation with all participants physically separated and teledebriefing with a videoconferencing platform.[10] Appendix A includes a brief overview of how to set up videoconferencing software for success as well as a link to a video from ACEP TeleSimBox. Use of breakout rooms for parent (embedded participant) discussion, as well as of the chat box, was reviewed as needed. Some sites had a dedicated manikin view available with which participants were able to visualize simulated patient changes in the physical exam. The scenario began with the patient off of cardiopulmonary monitors and without intravenous access. Throughout the scenario, the simulation facilitator provided clinical changes and exam findings verbally and made laboratory results and imaging available upon participant request. Chest radiographs and laboratory values were shared for participants to analyze. Other resources available to display included images of a rash, epistaxis, and ECG (Appendix B).

Personnel

This curriculum was implemented at five institutions in the United States (Yale-New Haven Children's Hospital, Seattle Children's Hospital, Vanderbilt Children's Hospital, Children's Wisconsin, and Phoenix Children's Hospital) with a range of one to five facilitators per session. A minimum of two faculty were required, one to provide patient exam data such as vitals and physical exam findings while also virtually implementing any orders from the team and the other to serve as an embedded participant in the role of parent.

Implementation

The simulation was incorporated into regularly scheduled PEM fellow simulations at the five institutions. Each session was 1 hour long, including the simulation and debrief. Appendix A was used as the scenario guide. At least four participants were required for each session. We assigned participants the roles of team lead, survey doctor, airway, and parent communicator. We designated any additional learners as observers and assigned them to fill out either the active observer critical action checklist or the active observer communication checklist (Appendix C or D, respectively) during the simulation. We counseled observers to turn their video off and mute themselves during the simulation to avoid distracting the active participants. While the case was designed for PEM fellows, residents, medical students, nurses, respiratory therapists, nurse practitioners, and physician assistants could also participate in potential roles outlined in Appendix A. When possible, participants should perform roles consistent with their clinical responsibilities for improved validity and application of knowledge gained.

The scenario began with the participants being told that a parent was presenting with a 6-year-old child with fever, fatigue, difficulty breathing, worsening headache, and new-onset rash. The team was informed by the bedside nurse that the patient was ill-appearing. A facilitator or an embedded participant playing the role of the parent provided history that the patient had experienced 3 days of fever, cough, congestion, headaches, and increased fatigue, as well as 1 day of epistaxis and diffuse rash. Additional history was available on participant request as outlined in Appendix A. After team members requested monitors to be applied to the patient, the vital signs were provided to the team via simulated monitors. The patient was initially febrile, with altered mental status and respiratory distress, requiring supplemental oxygen and fluid resuscitation. At team request, lab values for diagnostic workup consistent with hyperleukocytosis were provided (Appendix B).

The patient was subsequently noted to have both hyperkalemia due to TLS and DIC associated with hyperleukocytosis, which necessitated management with potassium and uric acid decreasing measures and blood products, respectively. Ultimately, the patient developed new-onset neurologic changes related to leukostasis secondary to hyperleukocytosis, which required an emergent head CT, placement of an advanced airway, and activation of the pheresis team, depending on institutional norms and practices. If the team requested a 12-lead ECG, they were provided with one (Appendix B) that was notable for peaked T waves. A chest X-ray was available (Appendix B) and notable for bilateral alveolar infiltrates. A head CT was available (Appendix B) and notable for intracranial hemorrhage.

At the conclusion of the clinical scenario, appropriate sign-out to the pediatric intensive care unit was expected. Appendix E provided a debriefing framework and a glossary of terminology for teamwork and communication, Appendix F provided a slide-based didactic, and Appendix G was the evaluation form for participants to complete after the case.

Debriefing

Facilitators utilized the PEARLS approach,[11] wherein facilitators were provided with a debriefing framework that could be tailored to various levels of learners and groups (Appendix E). Initial questions were intentionally broad and open-ended (e.g., "How did that feel?"), before progressing to a more structured discussion. Individualized experiences were used to tailor the discussion and provide specific feedback on teamwork and collaboration with the active observer critical action checklist (Appendix C) and the aid of active observer participants, if present, while also reinforcing key diagnostic and therapeutic learning points. Facilitators provided formative assessment using the active observer communication checklist (Appendix D) also with the aid of active observer participants, if present. A quick reference guide (Appendix F) was provided to facilitators to succinctly cover key learning points regarding hyperleukocytosis that could be utilized during the debrief as well.

Assessment

During the debriefing process, facilitators used the critical action checklist (Appendix C) to provide formative feedback to participants. Following the debriefing, participants completed a survey (Appendix G) to evaluate the simulation's ability to address the educational goals and objectives set forth by the team. Statements related to the realism and validity of the simulation and utility of the debrief were assessed via a 5-point Likert scale (1 = *strongly disagree,* 2 = *disagree,* 3 = *neutral,* 4 = *agree,* 5 = *strongly agree*). A free-text question was utilized to assess participants' self-report of knowledge: "Can you list/describe one or more ways this simulation session will change how you do your job?" To inform the iterative process, participants were also surveyed regarding suggestions to improve the scenario, as well as their experiences with virtual simulation. Specifically, given the relatively novel nature of virtual simulation, participants were asked about their number of prior virtual simulation experiences. This feedback was analyzed to improve the simulation in subsequent trials.

Results

The simulation curriculum was implemented at five different institutions, with surveys completed by 22 participants. Each of the 22 surveys was completed by a PEM fellow, with seven completed by first-year fellows, nine by second-year fellows, and six by third-year fellows. The survey included statements regarding personal clinical comfort/perceived competency with the evaluation and management of hyperleukocytosis (as laid out by the learning objectives) following the scenario and debrief. Participant scores for these statements are shown in Table 1.

Answers to open-ended questions concerning individuals' experience with the simulation such as "Can you list/describe one or more ways this simulation session will change how you do your job?" are summarized in Table 2 and included themes of expansion of differential diagnosis, importance of early notification of the intensive care unit, management of a complex patient presentation, and recognition of hyperleukocytosis.

Table 1. Simulation Evaluation Scores (*N* = 22)

Question[a]	*M*	*Mdn* [Range]
This experience was effective in meeting the learning objectives.	4.7	5 [3-5]
This simulation case was effective in teaching recognition of hyperleukocytosis.	4.8	5 [3-5]
I feel prepared to stabilize a patient with leukocytosis.	4.1	4 [3-5]
This simulation was effective in teaching the management of hyperleukocytosis.	4.6	5 [4-5]
I feel comfortable activating team assistance early in a resuscitative event.	4.7	5 [3-5]
This scenario allowed me to practice effective teamwork and communication skills.	3.9	4 [2-5]
Virtual (tele)simulation is effective compared to other distance learning methods (online case discussions, lectures, etc.).	3.9	4 [3-5]
Virtual (tele)simulation is effective compared to traditional in-person simulation/debriefing.	3.3	3 [2-5]

[a]Rated on a 5-point Likert scale (1 = *strongly disagree,* 2 = *disagree,* 3 = *neutral,* 4 = *agree,* 5 = *strongly agree*).

Table 2. Themes Obtained From the Self-Reported Knowledge Question "Can You List/Describe One or More Ways This Simulation Session Will Change How You Do Your Job?"

Theme	Representative Quotes
Expansion of differential diagnosis	"Broader differential for DIC."
Importance of early notification of the PICU	"I will notify PICU and oncology early for leukapheresis setup."
Management of complex patient presentation	"Helpful to see how the resus should run start to finish by a more senior fellow."
	"It helped me to appreciate how the eval/management should be organized."
	"There are multiple issues to address, but it is the role of the ED physician to recognize and treat the immediate life-threatening issues only."
Recognition of hyperleukocytosis	"Increased awareness of hyperleukocytosis in terms of diagnosis and management."
	"Great review of hyperleukocytosis."

Abbreviations: DIC, disseminated intravascular coagulation; ED, emergency department, PICU, pediatric intensive care unit.

Responses to "How can we improve this scenario?" (Table 3) included themes regarding changes to the environment of the simulation (e.g., distracting sound/alarms), difficulties with the virtual nature of the simulation (e.g., using multiple screens to view different portions, such as monitors, patient appearance, and record-keeping, simultaneously), and changes to the setup (e.g., smaller group sizes).

Of the 22 participants, 12 (54%) had participated in virtual simulation before, with a range of one to four previous experiences (*Mdn* = 2.5, *M* = 2.3). Of those with previous experience with virtual simulation, three participants were from

Table 3. Themes Obtained From the Question "How Can We Improve This Scenario?"

Theme	Representative Quotes
Changes to simulation environment	"The sound was distracting. It would be nice to silence both the alarms and the SpO2 monitor."
Difficulties with virtual simulation	"Could consider better sim software in the future."
	"Have one screen with the vitals monitor, patient appearance, record-keeping, meds given so that everyone can see everything that is happening."
	"Tough to only be able to gather information via 1 screen at a time."
No changes	"Excellent cases that were well presented."
	"Realistic—is encountered."
	"The tools and images used by the facilitator worked really well."
Changes in setup of simulation	"Smaller groups of fellows with two different sims would have been helpful."
Learning from observing colleagues	"Challenged the leader to break down multiple different systems and responses to treatments. Great learning experience."
	"Great to hear a senior fellow go through a complex case, learn thought process, how to manage, ways to improve."

Vanderbilt Children's Hospital, one was from Phoenix Children's Hospital, five were from Children's Wisconsin, three were from Seattle Children's Hospital, and none were from Yale-New Haven Children's Hospital.

Discussion

The purpose of this simulation curriculum was to train providers to recognize and appropriately manage pediatric hyperleukocytosis. The case allowed learners to review altered mental status and fever as potential presentations of hyperleukocytosis and to manage for potential complications such as hyperkalemia due to TLS, DIC, and sudden-onset neurologic changes.

This simulation was well received by participants overall, with most feeling that the simulation met its stated learning objectives and was effective in teaching both the recognition and management of hyperleukocytosis, as well as that learning objectives not adequately observed to have been met were discussed in the debriefing. The use of an active observer critical action checklist (Appendix C) and an active observer critical action communication checklist (Appendix D) allowed participants not directly participating in the clinical management of the telesimulation not only to engage in active observing but also to participate wholly in the debriefing. These optional observational checklists also provided extra roles in cases of larger learner groups. One learner suggested using smaller groups of learners in future iterations; the simulation can be tailored to do this, but it would not allow for active observation roles. A learner at one site reported to a facilitator that they encountered a similar patient presentation in the pediatric emergency department shortly after participating in the simulation and felt well prepared to manage the patient because of the simulation case.

Running this telesimulation provided valuable feedback on adapting and improving the presentation of a simulation in virtual format. Feedback spoke to the difficulties gathering information from one screen at a time, and participants suggested adapting software to be able to view vitals, patient appearance, and a running record of what had been completed to further mimic the reality of an emergency department. In subsequent iterations, we recommended having the embedded participant parent and assigned history-taker go into a breakout room or speak on the phone to minimize excess noise and chat in the chatbox, which was a well-received change. While there were some difficulties and areas for improvement in telesimulation, it was felt to be effective compared to other distance learning methods such as online case discussions/lectures. Participants felt more neutral about the effectiveness of this telesimulation as compared to traditional in-person simulation/debriefing, with a mean of 3.3 on the Likert scale. Although telesimulation had been utilized previously in some settings, there has been an increased use of this modality among our institutions due to the social distancing measures of the COVID-19 pandemic. Given the prolonged length of the COVID-19 pandemic and the necessity of simulation-based learning in medical education, one would expect these numbers to increase exponentially across all levels of learners, with many garnering more experience with virtual simulation out of necessity. Additionally, different formats of telesimulation are being developed throughout the pandemic, which offers opportunities to trial telesimulation cases such as this and gather learner feedback as many institutions continue to limit in-person simulation.

This resource provides a novel case of hyperleukocytosis recognition and management for the simulation literature, as well as an innovative look at the adaptation and running of a simulation in virtual format. In addition to being apropos considering current physical distancing requirements, this approach holds potential as a method of expanding simulation-based continuing medical education to settings with limited access. By utilizing existing institutional telecommunication resources, cost benefits are achieved by not requiring an in-person manikin or durable medical equipment. This modality offers both national and global applications in its potential to train providers across diverse settings spanning low-resource communities, rural areas, and the global arena as facilitators do not have to physically travel to effectively facilitate telesimulation. Further iterations of this simulation could be run in person as initially designed, as a complete telesimulation, or as an adapted hybrid model combining the two.

Limitations

A limitation in the analysis of this curriculum is that the simulation was run solely with first- through third-year PEM fellows. While the audience for the simulation (and thus the evaluation of its merits) was limited to fellows, the case with adaptations would be broadly applicable across the spectrum of learners who might care for sick pediatric patients, including pediatrics residents, family medicine residents, emergency medicine residents, medical students, respiratory therapists, nurses, nursing students, and mid-level providers. Adaptations to the case can be tailored to best serve the population of choice.

Technology limitations of this simulation include lack of visualization of completion of tasks given the virtual nature of the simulation and lack of physically completing a task for physical learning. There are also audio limitations given the software utilized, mainly the ability of only one person to be speaking at a time. Future iterations could consider other telesimulation modalities, such as the Virtual Resus Room,[12] for shared editing and a different sense of realism or could embed the video within a vital signs screen as opposed to using two different screens at the same time.

This curriculum was assessed largely via the Kirkpatrick model's level one,[13] as detailed above in the Results, and we did not explore changes in practice or patient outcomes. This could be improved by running the simulation with the same learners multiple times over a prolonged period with accompanying pre/post assessments. We utilized a convenience sample of learners, which could have implications for the generalizability of the study, but the multiregion nature of the participating institutions likely means that our results are generalizable to the broader population of learners. An additional limitation is the lack of measurement of the translation of knowledge acquired via the simulation to clinical practice.

Iterative Changes

Following the simulation's completion at multiple sites, the curriculum was adapted and improved utilizing the feedback provided, including minimizing noise with the videoconferencing platform and using smaller learner groups if preferred. Some videoconferencing software can use sticky notes or whiteboards or even share online documents to keep a record of the simulation, which can be trialed in future iterations. Facilitators reported that it was best to have a method of communication separate from videoconferencing that participants were not privy to, and this was trialed successfully in some iterations with group chatting apps. Additionally, early facilitators suggested that trialing the videoconferencing software prior to the actual simulation would be helpful in familiarizing them with the new modality; this approach was used in subsequent iterations and was reported as useful, so we added it to Appendix A. More broadly, as this simulation was run in a virtual manner, which had not been the norm in the past, unique feedback was garnered on ways in which to optimize/improve the realism of simulation-based learning when done virtually, such as by utilizing multiple screens so as to be able to simultaneously view multiple pieces of information (e.g., vitals, patient, labs).

Conclusion

Overall, this telesimulation PEM case was well received by learners. It can be adapted to the resources available at a given institution and can also be run in person, although that has not been attempted at our institutions given the ongoing COVID-19 pandemic. Future in-person iterations may require changes that were not assessed with this curriculum as it was developed. This telesimulation case curriculum will continue to be utilized across our institutions.

Appendices

A. Hyperleukocytosis Telesimulation Case.docx
B. Images and Laboratory Values.docx
C. Active Observer Critical Action Checklist.docx
D. Active Observer Communication Checklist.docx
E. Debriefing Materials.docx
F. Key Learning Points.pptx
G. Postsession Evaluation Form.docx

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

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