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Original Publication

Employing High-Fidelity Simulation for the High-Risk, Low-Frequency Diagnosis and Management of Acute Radiation Syndrome (ARS)

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Abstract

Introduction: Acute radiation syndrome (ARS) is a high-risk, low-frequency diagnosis that can be fatal and is difficult to diagnose without an obvious history of ionizing radiation exposure. **Methods:** Twenty-two emergency medicine residents and one pharmacy resident participated in an hour-long simulation session. To accommodate all learners, the simulation was conducted eight times over a block of scheduled time (two to four learners/session). Sessions included a prebriefing, pre/post questionnaires, the ARS case, and a debriefing. Learners evaluated and managed a 47-year-old male (manikin) with the hematopoietic and cutaneous subsyndromes of ARS who presented with hand pain/erythema/edema and underlying signs of infection 2 weeks after an unrecognized radiation exposure. Learners had to perform a history and physical, recognize/manage abnormal vitals, order/interpret labs, consult appropriate disciplines, and initiate supportive care. **Results:** There was a mean reported increase in ability to recognize signs and symptoms of ARS ($p < .001$) and appropriately manage a patient with this condition ($p = .03$) even after controlling for baseline confidence in ability to make and manage uncommon diagnoses, respectively. Learners rated this simulation as a valuable learning experience, effective in teaching them how to diagnose and treat ARS, and one they would recommend to other health care professionals. **Discussion:** This simulation aimed to teach the diagnosis and initial management of the hematopoietic and cutaneous subsyndromes of ARS. It should be used to increase awareness of the potential for ionizing radiation exposure under less obvious conditions and raise the index of suspicion for ARS in the undifferentiated patient.

Keywords
Acute Radiation Syndrome, CBRNE, Ionizing Radiation, Occupational Exposures, Uncommon Diagnosis, Case-Based Learning, Clinical Reasoning/Diagnostic Reasoning, Emergency Medicine, Simulation

Educational Objectives

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

1. Demonstrate the ability to effectively obtain a history and physical exam.
2. Recognize the signs and symptoms of the hematopoietic and cutaneous subsyndromes of acute radiation syndrome (ARS).
3. Provide appropriate supportive care to a patient presenting with the hematopoietic and cutaneous subsyndromes of ARS.
4. Identify appropriate subsyndrome-specific interventions for a patient presenting with the hematopoietic and cutaneous subsyndromes of ARS.

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Introduction

Without continual training, performance deteriorates over time, potentially placing patients at risk.[1,2] This is especially relevant for high-risk, low-frequency scenarios that do not occur often but require immediate competency once recognized. Simulation is one methodology used in the health care field to combat this deterioration by promoting clinical reasoning skills and technical proficiency in providers without harm to actual patients.[3,4] Acute radiation syndrome (ARS) is one of those high-risk, low-frequency scenarios.

ARS is a collection of dose-dependent signs and symptoms that manifests after a short-term exposure to high levels of external ionizing radiation.[5,6] Ionizing radiation in the context of ARS generally refers to penetrating electromagnetic radiation, such as gamma rays or X-rays, although neutron radiation can also cause ARS.[6] Another diagnostic criterion is that the entirety (or vast majority) of the individual's body must have received the dose of radiation.[7]

Because of its dose-dependent effects, ARS has been divided into four different subsyndromes named after the system affected at each dose threshold: hematopoietic (≥1 Gray [Gy]), cutaneous (≥3 Gy), gastrointestinal (≥6 Gy), and neurovascular (≥8 Gy).[7,8] Regardless of the subsyndrome, however, ARS progresses through four stages: prodromal, latent, manifest illness, and either recovery or death. The higher the dose, the faster the patient progresses through these stages.[7] In the hematopoietic subsyndrome, ionizing radiation damages radiosensitive lymphocytes and stem cells in the bone marrow, causing pancytopenia and predisposing the patient to opportunistic infections.[5,7-9] In the cutaneous subsyndrome, ionizing radiation can cause epilation, erythema, desquamation, and even radionecrosis, as the skin contains labile cells like those in the bone marrow and gastrointestinal tract.[5,7,10,11] In the gastrointestinal subsyndrome, damage to the bowel by ionizing radiation can cause a wide variety of issues, including hemorrhage, electrolyte abnormalities, and infection.[7] Finally, the neurovascular subsyndrome is associated with cerebral edema with diminishing consciousness, fever, and hypotension, amongst other findings.[7]

With these dose thresholds and subsyndromes in mind, it is important to note that ARS can be fatal without prompt diagnosis and treatment. The median lethal dose (LD_{50}) at 60 days without supportive care is 3.5-4.0 Gy but can increase to 5.0-6.0 Gy with supportive care.[7] Unfortunately, ARS has historically been diagnosed late in its course.[12] Moreover, without an obvious history of exposure, such as being involved in a nuclear explosion, ARS can be difficult to diagnose due to its nonspecific symptomatology.[6] Indeed, there are several examples in which individuals have been unknowingly exposed to radioactive materials and developed ARS.[13,14] In 2004 alone, there were over 5,000 known incidents in the US involving radioactive scrap metal, which is a potential source of exposure to radiation.[15] Thus, it is critical for emergency medicine (EM) physicians to be able to recognize, diagnose, and provide initial treatment to patients presenting with ARS, especially outside of the traditional mass casualty/weapons of mass destruction context. Nonetheless, ARS also remains relevant as the threat of nuclear warfare has continued to increase, further justifying the need for training.[16] In its model of the clinical practice of EM, the American Board of Emergency Medicine lists radiation emergencies under the list of conditions and components about which all board-certified EM physicians should be knowledgeable.[17] Yet EM physicians have been found to be underprepared for these situations.[18-20] Of the various educational strategies available, simulation uniquely provides the opportunity to encounter these rare clinical vignettes in a practical, realistic way, demanding the use of clinical reasoning and decision-making skills in real time. To our knowledge, there are no published simulations addressing ARS, an additional rationale for the development of this simulation.

Methods

Development

This hour-long simulation case (Appendix A) was primarily developed for teams of EM resident physicians. It was carried out during a regularly scheduled block of simulation time organized by the University of Alabama at Birmingham (UAB) Department of Emergency Medicine and was held at the Center for Patient Safety and Advanced Medication Simulation in coordination with the UAB Clinical Simulation Team. There were no preparatory activities or assignments required to participate in this simulation. The simulation project was exempt from further review by the UAB Institutional Review Board.

Equipment/Environment

The following equipment was used to implement the simulation case:

- Adult manikin capable of speech by way of a wireless/wired microphone and IV line placement.
- Diagnostic information, as provided in the supplemental case materials (Appendix B), including an image of an industrial radiography camera, the patient's extremity physical exam finding, EKG, X-ray imaging, and laboratory values.
- Monitor(s) capable of displaying the patient's noninvasive blood pressure, heart rate, pulse oximetry, temperature, laboratory values, EKG, and imaging.
- Noninvasive blood pressure cuff.
- Pulse oximeter.
- Bedside medical supply cart containing:
    - Three bags labeled lactated Ringer's or normal saline, vancomycin, and cefepime.
    - Pill container labeled acetaminophen.
- Headsets for communication between the scenario director, simulation technician, and embedded simulation person (ESP).

Personnel

This simulation required three personnel to fill the following roles: ESP (nurse), simulation technician, and scenario director. The ESP acting as a nurse was responsible for introducing learners to the patient (giving the scenario stem), supplying the image of the physical exam finding, clarifying findings as requested, answering any questions about available resources, and providing the image of the industrial radiography camera, as detailed in Appendix A. The simulation technician was responsible for changing the patient's vital signs on the monitor after appropriate interventions and uploading diagnostic information (lab values, imaging) to the monitor after it had been ordered by the learners. The scenario director was a board-certified EM physician who voiced the manikin and any consultants called by the learners, completed the critical actions checklist (Appendix C), and communicated with the ESP and simulation technician to ensure the proper flow of the case. If additional personnel were available, they could be utilized to assist the scenario director by helping complete the critical actions checklist and/or communicating with the other personnel via headset.

Implementation

As previously stated, learners were not assigned any preparatory readings or activities prior to participating in the simulation. After entering the simulation center, learners were asked to complete the presimulation questionnaire (Appendix D). This questionnaire obtained demographic information regarding the learners' position and level of training and assessed the following: (a) degree of confidence in performing a history and physical exam and in making and managing an uncommon diagnosis; (b) degree of belief in the educational usefulness, enjoyment, and applicability of simulations; and (c) amount and availability of professional training in uncommon diagnoses. The scenario director then conducted a prebriefing in which the learners, all having participated in simulations before, were reminded of how to interact with manikins in the immersive simulated environment, case confidentiality, physical and psychological safety, the fiction contract, and the basic assumption.[21]

Following the prebriefing, the ESP brought the group of learners (two to four individuals) down the hall to outside the simulated emergency department (ED) patient room. Before learners were allowed to open the privacy curtain and enter the room, the ESP briefed them on the ESP's role, as detailed in the simulation case (Appendix A), and presented the scenario stem (patient's name, age, chief complaint, and setting). Learners were then instructed to perform a history and physical, recognize and manage abnormal vitals, order and interpret labs, consult appropriate disciplines, and initiate supportive care.

The scenario director and simulation technician were in a separate room that was technologically equipped to provide audio and visual feedback to the learners as they proceeded through the case. In this room, the scenario director was also able to communicate with the learners through a microphone that could be switched from voicing the manikin to voicing consults, the latter of which involved an intercom system in the ceiling of the simulated ED patient room. Additionally, the simulation technician could change the manikin's vital signs at specific branch points and upload requested labs and imaging from this room.

After the case, the scenario director exited this room and met with the learners for a bedside debriefing (Appendix E). Finally, learners completed the postsimulation questionnaire (Appendix D). This questionnaire asked the same learner confidence questions as in the presimulation questionnaire to assess change in confidence to diagnose and manage uncommon diagnoses. The postsimulation questionnaire also assessed change in confidence in recognizing and managing ARS specifically by asking questions in relation to during and after the simulation. These ARS-specific questions were not asked in the presimulation questionnaire as foreknowledge of the condition being simulated could have biased postsimulation responses. The postsimulation questionnaire also assessed the degree of educational value of this particular ARS simulation and invited open-ended comments on the simulation's strengths and areas for improvement.

Debriefing

Following the simulation case, learners participated in a 15-minute bedside debriefing led by the scenario director. They were first given an opportunity to reflect on the simulation experience and verbally express their reactions before the scenario director presented the facts of the case. Using a $+/\Delta$ framework for debriefing, learners were able to discuss areas of strength and improvement.[22] Finally, the scenario director facilitated a discussion on the diagnosis and management of ARS. Detailed debriefing materials for this simulation are provided in Appendix E.

Assessment

The scenario director filled out critical actions checklists (Appendix C) for each group of learners as they completed the case (a total of eight completed checklists). Critical actions were established by considering the current standards of care for EM physicians. The subsequent debriefing provided learners with formative feedback on their clinical reasoning and decision-making processes, as well as additional knowledge on the pathophysiology, diagnosis, and management of ARS. Pre- and postsimulation questionnaires were completed individually by all the learners ($N = 23$). The questionnaires included confidence statements that learners rated on a 7-point Likert-type scale (0 = *Strongly disagree,* 1 = *Disagree,* 2 = *Slightly disagree,* 3 = *Neutral,* 4 = *Slightly agree,* 5 = *Agree,* 6 = *Strongly agree*).

Analyses
Data from the pre- and postsimulation questionnaires were tested for normality with histograms, means, and standard deviations. Values with standard deviations greater than 3.0 were removed. A paired-samples *t* test assessed presimulation versus postsimulation difference scores with bias-corrected Hedges' *g* for effect size: small ($g = 0.20$), medium ($g = 0.50$), and large ($g = 0.80$). Pearson's *r* determined correlations between (a) PGY and baseline confidence in performing a history and physical exam and (b) PGY and baseline confidence in working as a member of a multidisciplinary team. Data are reported as means and standard deviations, with alpha set at .05 for significance. SPSS version 27 was used. Critical actions checklist results are presented as percentages.

Results

Learners
Twenty-two EM resident physicians and one pharmacy resident participated in this simulation. The simulation was conducted back-to-back eight times during a block of scheduled simulation time in June 2022 to accommodate all learners (two to four per session). Thus, all learners were nearing the end of their respective PGY. Among the EM residents, seven were PGY 1, six were PGY 2, and nine were PGY 3. The pharmacy resident was a PGY 2. There was an association between PGY and baseline confidence in performing a history and physical exam ($r = .52$, $p = .01$, $N = 22$, $M = 5.1$, $SD = 0.7$, *Agree*).

Objective Outcomes: Confidence in Making and Managing an ARS Diagnosis
Regarding reported confidence ratings in the ability to make an uncommon diagnosis, there was an increase after the simulation from $M = 4.0$ ($SD = 0.9$), *Slightly agree,* to $M = 4.6$ ($SD = 0.9$), *Slightly agree–Agree* ($p = .02$, $N = 21$, $g = 0.56$). Reported confidence in managing an uncommon diagnosis also increased from $M = 3.7$ ($SD = 0.9$), *Neutral–Slightly agree,* to $M = 4.4$ ($SD = 0.9$), *Slightly agree* ($p = .002$, $N = 22$, $g = 0.67$). Confidence in recognizing the signs and symptoms of ARS after the simulation increased compared to during the simulation from $M = 3.6$ ($SD = 1.9$), *Neutral–Slightly agree,* to $M = 5.1$ ($SD = 0.6$), *Agree* ($p < .001$, $N = 23$, $g = 1.00$). Similarly, reported confidence in managing ARS after the simulation increased compared to during the simulation from $M = 4.5$ ($SD = 1.1$), *Slightly agree–Agree,* to $M = 5.1$ ($SD = 0.7$), *Agree* ($p = .03$, $N = 19$, $g = 0.60$). Controlling for baseline confidence in ability to make and manage uncommon diagnoses did not affect these significant ARS-specific outcomes.

Need and Desire for Training in Uncommon Diagnoses
The learners' mean rating was between *Neutral* and *Satisfied* when considering the availability of continuing education activities that focus on uncommon conditions and their exposure to uncommon conditions in simulation training (Table 1). Learners also reported only occasionally participating in continuing education activities that focus on uncommon conditions. Finally, the learners' mean rating was between *Agree* and *Strongly agree* when reporting their desire to receive more simulation-based training on the diagnosis and management of uncommon conditions. Review of the critical actions checklists revealed that all learner groups appropriately administered fluids and an antipyretic/analgesic and that seven of the eight groups appropriately administered broad-spectrum antibiotics. However, despite providing overall good supportive care, six of the eight groups of learners (75%) required prompting with the image of the industrial radiography camera (containing the radiation warning symbol) to ultimately recognize the exposure to ionizing radiation and make the diagnosis. This further validated the need for this type of training.

Quality of ARS Simulation
The mean response for all questions related to the educational value and other benefits of the simulation for the learners was between *Agree* and *Strongly agree*. Table 2 presents a complete list of the simulation attributes assessed. The most frequently reported strengths of this ARS simulation on the open-ended section of the postsimulation questionnaire included the following: good topic ($N = 9$) and increased awareness of a diagnosis learners would not otherwise have thought about ($N = 5$): for example, "Something I've read about but not seen" and "It broadens the thought process about exposures." Another reported strength was that the simulation "requires a more slowed, methodical approach versus typical crashing sim patients."

Discussion

This simulation aimed to increase EM resident physicians' awareness and knowledge of the signs and symptoms of ARS and the initial management of a patient experiencing two of its subsyndromes. Analysis of the self-reported pre- and

Table 1. Availability of Training on and Exposure to Uncommon Diagnoses

Question[a]	*M* (*SD*)	Corresponding Rating
1. My professional training program (i.e., residency program, nursing/advanced practice provider school, pharmacy school) has offered or did offer adequate training on the diagnosis and management of uncommon conditions.[b]	4.7 (0.9)	Slightly agree–Agree
2. With regard to continuing education activities for licensure renewal, how often do the activities you participate in focus on the diagnosis and/or management of uncommon conditions?[c]	3.0 (0.4)	Occasionally
3. With regard to continuing education activities for licensure renewal, how satisfied are you with the availability of activities focusing on the diagnosis and/or management of uncommon conditions?[d]	2.8 (0.8)	Neutral–Satisfied
4. With regard to the clinical environment in which you currently work, how satisfied are you with your exposure to uncommon conditions?[d]	3.0 (0.7)	Satisfied
5. With regard to training in the simulation environment, how satisfied have you been with your exposure to uncommon conditions?[d]	2.9 (0.8)	Neutral–Satisfied
6. Residents/trainees only: With regard to program didactics, how satisfied are you with your exposure to uncommon conditions?[d]	3.0 (0.8)	Satisfied
7. I would like to receive more simulation-based training on the diagnosis and management of uncommon conditions.[b]	5.5 (0.5)	Agree–Strongly agree

[a]*N* = 23 for all questions except question 6, where *N* = 22, as one learner left it unanswered.
[b]Agreement rated on a 7-point Likert-type scale (0 = *Strongly disagree,* 6 = *Strongly agree*).
[c]Frequency rated on a 5-point Likert-type scale (0 = *Never,* 4 = *Very frequently*).
[d]Satisfaction rated on a 5-point Likert-type scale (0 = *Very dissatisfied,* 4 = *Very satisfied*).

postsimulation questionnaires revealed increased confidence in the ability to make and manage uncommon diagnoses. More importantly, learners reported increased confidence after the simulation versus during the simulation in their ability to diagnose and initially manage patients with ARS (hematopoietic and cutaneous subsyndromes), even after controlling for baseline confidence in diagnosing and managing uncommon conditions.

We acknowledge a few limitations that should be considered and addressed for future implementations of this simulation. The number and experience of our learners varied per session; future implementations should consider matching groups based on PGY level and number of learners per group. The simulation case could also benefit from the following: (a) inclusion of a urine drug screen and heavy metal blood test results; (b) adaptation to include a patient contaminated with, not just exposed to, radioactive material; (c) addition of a prehospital component for emergency medical technician and paramedic learners; and (d) addition of a control group using another educational modality for learning about ARS to test the advantage of simulation learning.

Despite these limitations, learners endorsed the rigor and value of this simulation and strongly agreed that they would recommend it to health care professionals at other institutions. Importantly, they also reported a need and desire for training on uncommon conditions. The fact that 75% of learner groups required prompting with the image containing the radiation warning symbol to recognize ionizing radiation exposure speaks to the importance of this simulation regarding health care preparedness for uncommon conditions and chemical, biological, radiological, nuclear, and explosive (CBRNE) events. Multiple studies have already evidenced a deficiency in responder/provider preparedness for such events.[23-25] Although malicious intent was not behind the radiation source in this simulation, we presume that health care preparedness for patients affected by CBRNE hazards under less obvious conditions, such as in this simulation case, may be even more deficient. Thus, we propose that this novel simulation case be utilized to educate health care professionals on the health effects of ionizing radiation, increase awareness of the potential

Table 2. Simulation Attitudes and Effectiveness (*N* = 23)

Question[a]	*M* (*SD*)	Corresponding Rating
1. This simulation was a valuable learning experience.	5.5 (0.5)	Agree–Strongly agree
2. This simulation was challenging.	5.6 (0.5)	Agree–Strongly agree
3. This simulation increased my awareness about ARS.	5.6 (0.5)	Agree–Strongly agree
4. This simulation was effective in teaching me how to diagnose and treat ARS.	5.4 (0.5)	Agree–Strongly agree
5. This simulation was one that I would recommend to health care professionals at other institutions.	5.5 (0.5)	Agree–Strongly agree
6. The debrief promoted a safe environment for discussion and reflection.	5.5 (0.5)	Agree–Strongly agree

Abbreviation: ARS, acute radiation syndrome.
[a]Rated on a 7-point Likert-type scale (0 = *Strongly disagree,* 6 = *Strongly agree*).

for ionizing radiation exposure under more inconspicuous conditions, and raise the index of suspicion for ARS in the undifferentiated patient.

Appendices

A. Simulation Case.docx

B. Supplemental Case Materials.pptx

C. Critical Actions Checklist.docx

D. Learner Questionnaires.docx

E. Debriefing Materials.docx

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

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Ethical Approval
The University of Alabama at Birmingham Institutional Review Board deemed further review of this project not necessary.

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