ORIGINAL ARTICLE

High-Fidelity Contrast Reaction Simulation Training: Performance Comparison of Faculty, Fellows, and Residents

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Abstract

Purpose: Reactions to contrast material are uncommon in diagnostic radiology, and vary in clinical presentation from urticaria to life-threatening anaphylaxis. Prior studies have demonstrated a high error rate in contrast reaction management, with smaller studies using simulation demonstrating variable data on effectiveness. We sought to assess the effectiveness of high-fidelity simulation in teaching contrast reaction management for residents, fellows, and attendings.

Methods: A 20-question multiple-choice test assessing contrast reaction knowledge, with Likert-scale questions assessing subjective comfort levels of management of contrast reactions, was created. Three simulation scenarios that represented a moderate reaction, a severe reaction, and a contrast reaction mimic were completed in a one-hour period in a simulation laboratory. All participants completed a pretest and a posttest at one month. A six-month delayed posttest was given, but was optional for all participants.

Results: A total of 150 radiologists participated (residents = 52; fellows = 24; faculty = 74) in the pretest and posttest; and 105 participants completed the delayed posttest (residents = 31; fellows = 17; faculty = 57). A statistically significant increase was found in the one-month posttest ($P < .00001$) and the six-month posttest scores ($P < .00001$) and Likert scores ($P < .001$) assessing comfort level in managing all contrast reactions, compared with the pretest. Test scores and comfort level for moderate and severe reactions significantly decreased at six months, compared with the one-month posttest ($P < .05$).

Conclusions: High-fidelity simulation is an effective learning tool, allowing practice of "high-acuity" situation management in a nonthreatening environment; the simulation training resulted in significant improvement in test scores, as well as an increase in subjective comfort in management of reactions, across all levels of training. A six-month refresher course is suggested, to maintain knowledge and comfort level in contrast reaction management.

Key Words: Contrast reaction, contrast, education, simulation, team training, high-fidelity

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INTRODUCTION

Iodinated intravenous contrast material was first administered in the 1920s and remains one of the most frequently administered intravenous medications to improve soft-tissue contrast in radiology [1]. Administration can result in both nonallergic and allergic-like adverse reactions, encompassing a wide spectrum of clinical symptoms ranging from simple urticarial reactions to life-threatening anaphylaxis. The supervising physician is responsible for recognizing the symptoms and providing appropriate management of contrast reactions [2]. Most radiologists have limited experience managing severe reactions, and more than 50% of radiologists do not know the correct dose of epinephrine to administer during a severe reaction [3,4]. This lack of knowledge is a significant problem, especially because a radiologist may be the sole provider during a life-threatening reaction [5].

High-fidelity simulation has emerged as a viable method to educate radiologists about proper contrast-reaction management that is effective and cost efficient [2,6-9]. In addition, such simulation provides an opportunity to

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practice administering medications such as epinephrine, and can serve as a review of basic life-support management [6,10,11].

Using high-fidelity simulation, we instituted a department-wide quality improvement program aimed at increasing patient safety and knowledge regarding management of contrast reactions. The purpose of our study was to assess comfort and knowledge regarding the management of contrast reactions, and reaction mimics, before simulations, at one month and six months after completion of a one-hour high-fidelity simulation session among residents, fellows, and attending radiologists of various experience levels. Assessing the benefits of simulation across all levels of training provides a means to study a population who vary in age and experience. In addition, this type of assessment more accurately reflects actual clinical practice, in which any type of radiologist (trainee or senior faculty) may be called on to respond to a potential contrast reaction.

METHODS

An institutional review board—approved, HIPAA-compliant, quality improvement project was developed for all residents, fellows, and faculty to participate in a program reviewing the management of contrast reactions and contrast reaction mimics. We defined a contrast reaction mimic as a potentially life-threatening event (such as a seizure or hypoglycemic event) that could occur in a radiology department and is unrelated to the administration of intravenous contrast. For our study, informed consent was waived; however, all participants had the ability to request that their specific test results not be included for analysis.

A 20-question multiple-choice pretest was created, based on the ACR 2013 contrast manual, to assess baseline knowledge with Likert-scale questions assessing subjective comfort in managing contrast reactions and perceived effectiveness of simulation-based training, including assessment of group size, simulation training as a learning tool, frequency of simulation training, and use of other forms of simulation training within the department [12]. Participant demographics, level of training, and basic life support/advanced cardiac life support (BLS/ACLS) certification status were recorded (Appendix 1, available online). Testing was completed via participant-specific online links, distributed using e-mail via Qualtrics Labs (Provo, Utah) survey/testing software before, one month after, and six months after simulation session training.

All residents and fellows within our department were required to participate in the simulation training, which included taking a pretest and a posttest. Participation was optional, but was a factor in bonus eligibility, for faculty members. As determined by the departmental leadership, the six-month posttest was optional for all participants, because it was not felt to be a critical component of the overall quality improvement project.

Pre-Simulation Testing

Each participant received an e-mail with a unique link to complete the pretest. Participants were asked to refrain from using any references or sharing answers while completing the test. Once the pretest was completed, participants were able to schedule themselves for a one-hour simulation course via an internal website created by our institution's IT staff.

Simulation Laboratory Procedure

After pre-simulation testing, participants completed a one-hour simulation session designed to practice the management of a moderate-severity contrast reaction, a high-severity contrast reaction, and a hypoglycemic event that mimicked a contrast reaction within our institution's high-fidelity simulation laboratory. A total of 29 simulation sessions were given, each lasting one hour, occurring over 40 days in September 2013 and October 2013 between 8:00 AM and 4:00 PM. Sessions were held on various days of the week and at various times, to facilitate completion for participants.

All sessions were conducted in a high-fidelity simulation laboratory, with groups of eight to ten participants. Groups were a mixture of residents, fellows, and faculty, with two to three people serving as "responders" for each simulation, and the remaining participants watching via video in real time in an adjacent room. In some sessions, radiology nurses were present; if they were not available, the role of a radiology nurse was played by the simulation instructor.

The simulation room was set up as a standardized hospital room at our institution, and all participants had access to a code cart and our department's contrast reaction kit. The kit included the following medications: an albuterol nebulizer, 100 mg hydrocortisone, 50 mg intravenous and/or intramuscular diphenhydramine, 1 mg atropine, 10 ml (1 mg) of a 1:10,000 concentration of epinephrine vial/bristojet, and a 1 ml (1 mg) vial of a 1:1,000 concentration of epinephrine. During the simulation, participants were instructed to interact with the mannequin (SimMan, Laerdal Medical Corp, Wappingers Falls, New York) as if it were an actual

patient. The mannequin had the capability to receive medications, display continuous real-time vital signs (which were easily changed during scenarios), and manifest physical examination findings, such as wheezing, crackles, tongue/laryngeal edema, and diaphoresis. The technician operating the mannequin was able to provide verbal responses to questions asked by responders via built-in speakers and could hear/see participants via real-time video. Urticaria was simulated via blush makeup application to the mannequin "skin" by simulation center staff.

Each simulation was followed by a five- to ten-minute debriefing session in an adjacent classroom, where participants discussed what occurred, and trainers reviewed the appropriate treatment algorithm verbally and via PowerPoint (Microsoft, Redmond, Washington) slides. The simulation staff consisted of a simulation instructor from radiology, who guided participants through each simulation; a high-fidelity mannequin controlled by a dedicated simulation operations technologist; and a simulation laboratory supervisor to oversee all the simulations. The simulation instructors were four radiologists (three faculty members and one resident) who were certified in simulation instruction after completion of an eight-hour simulation science course at our institution.

Simulation Content

Three high-fidelity simulation scenarios were developed by two of the radiology instructors. Each scenario was designed to reflect specific predetermined learning objectives and endpoints (Table 1). Treatment criteria algorithms were developed based on author experience, the 2013 ACR Manual on Contrast Media [12], and clinical support applications, such as UpToDate Anywhere (Wolters Kluwer Health, Philadelphia, PA).

Postsimulation Testing

Within one month of completing the simulation, each participant completed the posttest via a unique participant web link, to reassess knowledge and comfort level regarding management of contrast reactions (herein referred to as "posttest"). The same test was readministered at six months after simulation (herein referred to as "delayed posttest"), via the same method.

Data Analysis

Statistical computations and analyses were performed with Excel (Microsoft) and R (The R Foundation for Statistical Computing, www.r-project.org). Categoric baseline variables were summarized as number (%). Test scores were summarized by mean correct (% correct). Multiple-choice

Table 1. Three contrast reaction scenarios, with overall treatment algorithms, used in high-fidelity simulation training of 150 radiology residents, fellows, and faculty

Scenario	Treatment Algorithm
Mild contrast reaction progressing into a moderate contrast reaction: urticaria unresponsive to diphenhydramine with development of bronchospasm with wheezing, cough, and declining oxygen saturations	1. Obtain past medical history. 2. Place patient on monitor and obtain vital signs. 3. Recognize the scenario as a contrast reaction and administer 25-50 mg of diphenhydramine IV or PO. 4. After no relief and progression of symptoms to diminished oxygen saturations, administer albuterol nebulizer and 0.3 mg epinephrine 1:1,000 IM. 5. Know how to, and initiate, hospital's code team.
Hypoglycemic event: diaphoresis, slight tachycardia, altered mental state	1. Obtain past medical history from patient/technologist. 2. Place patient on monitor and obtain vital signs. 3. Recognize hemodynamic stability and possible contrast reaction mimic. 4. Check finger stick glucose (value = 25-50). 5. Administer 1 amp of D50 IV push.
Severe contrast reaction: tongue and laryngeal edema, wheezing/coughing, hypotension, falling oxygen saturations, tachycardia, tachypnea, and declining consciousness	1. Obtain past medical history. 2. Place patient on monitor and obtain vital signs. 3. Recognize this scenario as a severe or "anaphylactic" contrast reaction. 4. Administer oxygen via nonrebreather for hypoxia. 5. Administer epinephrine 1:10,000 (0.1-0.3 mg) via slow IV push ± albuterol nebulizer. 6. Know how to, and initiate, hospital's code team.

Note: All patients were said to have just completed a CT scan of the abdomen and pelvis, with iodinated contrast. IM = intramuscular; IV = intravenous; PO = oral.

test scores were compared with paired two-tail t tests; Likert scores were compared using the Wilcoxon signed rank test. Scores were visually inspected to confirm the reasonableness of the assumption that the means were approximately normally distributed. The distribution among participants (residents versus fellows versus faculty) for the delayed posttest was assessed via χ^2 analysis. A P value of <.05 was considered statistically significant.

RESULTS

A total of 151 of 161 available participants completed the simulation; one faculty member's results were removed from data analysis per the choice of that participant. In all, 150 participants completed the pretest and posttest—102 (68%) men and 48 (32%) women. The average age was 40 years (range: 27-83 years). Experience level was broken down by year for residents, fellow status (its own category), and years of practice for faculty (Table 2). Those who did not complete the simulation included: two residents (first year; on vacation/leave); and eight faculty members with varying experience levels (one with <5 years; one with 6-10 years; and six with >15 years).

Participation was optional and was not part of bonus eligibility for three of the eight faculty members, because they do not administer intravenous iodinated contrast in their work, which includes only nuclear medicine, fluoroscopy, and ultrasound. The remaining five of the eight chose not to participate. Participation for the first-year residents was 86%; for faculty, participation varied by years of experience, with 96% for 0-5 years, 90% for 6-10 years, and 83% for >15 years. All other subgroups had 100% participation in the simulation, including the pretest and posttest.

The simulation sessions were well received; 86% of participants asked for other forms of simulation to be conducted in our radiology department. A total of 93% of participants thought the group size was adequate; 57% thought the simulation should be completed annually.

The mean overall score on the pretest was 14.1 of 20 possible points (SD: 2.4; range: 5-19). Across all participants, the average test score increased significantly in the posttest to 16.0 ($P \leq .00001$). When the test scores were analyzed by subgroup, all resident subgroups showed a significant change, as well as faculty who had <5 or >15 years of experience. No significant change occurred in the other groups (Table 3).

The delayed posttest had 105 participants (69%). The ratio of residents, fellows, and faculty who participated in the delayed posttest (n = 105) was not statistically different ($P = .93$) from the ratio who took the pretest or posttest (n = 150) (Table 2). Overall, test scores increased from 14.1 before the simulation, to 16.0 at 6 months after ($P < .00001$). By subgroup analysis, residents, as well as faculty with either <5 or >15 years of experience had a statistically significant score improvement (Table 3).

An overall decrease in test scores across all subgroups was noted for the delayed posttest compared with the posttest (16.0 to 15.6; $P = .01$). By subgroup analysis, only the fourth-year residents demonstrated a significant decrease in test scores from the posttest to the delayed posttest (Table 3).

Responses to all Likert-scale questions gauging comfort level in managing reactions demonstrated a significant positive increase ($P < .001$) from pretest to posttest. The overall comfort level in managing reactions remained significantly improved on the delayed posttest, compared with presimulation ($P < .001$), but showed a significant decline ($P = .03$) compared with the posttest (Table 4).

A significant increase was found in support of high-fidelity simulation training as an effective learning tool for contrast reaction management after completion of the simulation (4.0 versus 4.5, $P < .001$), and this persisted at the delayed posttest (4.0 versus 4.5, $P < .001$). Participants felt more comfortable differentiating a contrast reaction from a contrast reaction mimic (3.1 versus 3.9, $P < .001$), a difference that remained at the delayed posttest (3.9, $P < .001$). In addition, participants felt more comfortable in differentiating mild contrast reactions from severe contrast reactions at both posttests, compared with the pretest ($P < .001$; Table 4).

Table 2. Breakdown of participation level of the 150 radiology residents, fellows, and faculty participants in a high-fidelity contrast reaction management simulation training, by radiology experience level (PGY)

Experience Level	Pretest and Posttest n (%)	Delayed Posttest n (%)
Residents		
First year (PGY 2)	12 (8)	9 (9)
Second year (PGY 3)	14 (9)	8 (8)
Third year (PGY 4)	13 (9)	4 (4)
Fourth year (PGY 5)	13 (9)	10 (10)
Fellows	24 (16)	17 (16)
Faculty, by practice level (y)		
0–5	27 (18)	23 (22)
6–10	9 (6)	7 (7)
11–15	9 (6)	6 (6)
>15	29 (19)	21 (20)
Total	150	105

Note: Pretest, posttest, and delayed posttest were given to participants before, one month after, and six months after simulation training, respectively. PGY = postgraduate year.

Table 3. Mean multiple-choice test scores, overall, and by level of training, of participants in a high-fidelity contrast reaction management simulation training of 150 radiology residents, fellows, and faculty

Participants	Pretest Score	Posttest Score	Delayed Posttest Score	P Value: Pretest vs Posttest	P Value: Posttest vs Delayed Posttest	P Value: Pretest vs Delayed Posttest
All (N = 150)	14.1 (70)	16.0 (80)	15.6 (78)	<.00001*	.01*	<.00001*
Residents						
First year (n = 12)	12.9 (65)	15.5 (78)	16.6 (83)	.03*	.12	.012*
Second year (n = 14)	12.7 (63)	15.9 (80)	13.9 (69)	.001*	.09	.02*
Third year (n = 13)	13.7 (68)	15.5 (78)	15.0 (75)	.003*	.39	.68
Fourth year (n = 13)	14.8 (74)	16.9 (85)	14.9 (75)	.002*	.01*	.54
Fellows (n = 24)	14.3 (72)	15.6 (78)	15.3 (76)	.06	.70	.24
Faculty, by experience level (y)						
<5 (n = 27)	14.4 (72)	16.3 (82)	16.0 (80)	.00001*	.13	.0001*
6–10 (n = 9)	14.0 (70)	15.9 (79)	15.0 (75)	.13	.63	.08
11–15 (n = 9)	15.2 (76)	16.1 (81)	16.0 (80)	.30	.61	.17
>15 (n = 29)	14.2 (71)	16.3 (81)	16.0 (80)	<.00001*	.20	.001*

Note: Pretest, posttest, and delayed posttest were given to participants before, one month after, and six months after simulation training, respectively. Numbers in parentheses indicate % correct of 20.
*Statistically significant.

No significant difference in pretest scores was noted when participants were stratified by BLS and/or ACLS certification (14.1 versus 14.3, $P = .64$). Those who were ACLS noncertified scored higher than those who were ACLS certified, on the posttest ($P = .01$) as well as the delayed posttest ($P = .03$) (Table 5). In addition, those who were BLS noncertified scored significantly higher on the delayed posttest ($P = .02$) (Table 5).

DISCUSSION

Contrast reactions are one of the few medical emergencies encountered in diagnostic radiology, and the ability to appropriately manage a reaction is essential for the supervising radiologist. However, owing to the relative infrequency of contrast reactions, radiologist knowledge about their management is often insufficient [3,13]. Most physician education on contrast reaction management is gained through didactic lectures; relatively few programs use simulation training [14].

However, studies have demonstrated that high-fidelity contrast simulation is superior to such lectures alone in teaching appropriate management of high-acuity but low-frequency events, such as severe contrast reactions [5,10,15]. Advantages of simulation include tailoring the simulation to each individual participant or

Table 4. Mean comfort values in managing contrast reactions, as self-rated by 150 radiology residents, fellows, and faculty participants in a high-fidelity simulation training

Comfort Dimension	Pretest Comfort Level	Posttest Comfort Level	Delayed Posttest Comfort Level	P Value: Pretest vs Posttest	P Value: Posttest vs Delayed Posttest	P Value: Pretest vs Delayed Posttest
Overall, in managing reactions	2.9	3.7	3.5	<.001	.03	<.001
Managing mild reactions	3.7	4.4	4.3	<.001	.33	<.001
Managing moderate reactions	3.0	3.9	3.7	<.001	.004	<.001
Managing severe reactions	2.4	3.4	3.1	<.001	.03	<.001
Differentiating a reaction from another medical emergency	3.1	3.9	3.9	<.001	.36	<.001
Differentiating a mild from a severe reaction	3.6	4.1	4.2	<.001	.4	<.001

Note: Pretest, posttest, and delayed posttest were given to participants before, one month after, and six months after simulation training, respectively. Range of comfort values is 1 (not comfortable at all) to 5 (very comfortable).

Table 5. Mean test scores, broken down by whether or not participants were ACLS or BLS certified

Certification Status	Pretest Score	Posttest Score	Delayed Posttest Score
ACLS certified	14.1	15.7	15.2
ACLS noncertified	14.3	16.6	16.0
P value (certified vs noncertified)	.64	.01*	.03*
BLS certified	14.1	15.9	15.3
BLS noncertified	14.5	16.4	16.3

Note: Pretest, posttest, and delayed posttest were given to participants before, one month after, and six months after simulation training, respectively. ACLS = advanced cardiac life support; BLS = basic life support.
*Statistically significant.

group, making mistakes in a protected environment without harming actual patients, and postsimulation debriefing. The latter provides a structured session designed for participants to reflect on overall performance; it has been shown to be an effective learning tool and an integral part of simulation participation [16].

Our results (Table 3) are consistent with studies that have shown the effectiveness of high-fidelity simulation in improving knowledge of contrast reaction management [5,6,9-11,14,17,18]. However, unlike other studies, our study additionally evaluated subgroup performance based on level of training, as well as retention at six months (Table 3). Assessment of the effectiveness of high-fidelity simulation training is important across all physician skill levels for several reasons. First, it allows identification of areas or groups in which participants need additional training on a particular skillset, such as proper epinephrine dosage and administration. Second, it builds teamwork and communication skills between varying levels of physicians, from junior residents to senior faculty and administration. Finally, it provides a more accurate evaluation of the effects of simulation training and allows for increased physician knowledge and patient safety.

Although overall test scores increased from the pretest to the delayed posttest (14.1 versus 15.6, $P < .00001$), we did note a significant decrease in overall test scores (16.0 versus 15.6, $P = .01$) on the posttest compared with the delayed posttest. The simulations additionally resulted in a significant increase in participant comfort level in managing contrast reactions of all severities, highlighting the acceptance and perceived benefit of simulation in teaching reaction management. As with the test scores, we found a significant decline in comfort level on the delayed posttest, compared with the posttest

(Table 4), especially for severe reactions. This finding confirms an overall decline over time in both knowledge and comfort in managing contrast reaction, although the score differences were not statistically significant for all subgroups.

Our study does differ from prior work in several respects. Many studies that have assessed simulation effectiveness involved smaller sample sizes or did not include faculty [2,14-16]. Assessing the effect of high-fidelity simulation across all levels of training is imperative as it allows for a more accurate evaluation of the impact of participant age, experience, and comfort level with new technology. In addition, such simulation more closely mimics the actual clinical practice setting, in which the particular radiologist who is asked to respond to a potential reaction varies based on practice environment (ie, academic versus private practice, or inpatient versus outpatient location).

Additionally, we assessed the relationship of BLS and ACLS training with test performance. To our surprise, we did not see a significant trend in improvement based on ACLS or BLS status. In fact, those who were not certified in ACLS scored better on the posttest and delayed posttest. This finding suggests that contrast reaction management is not significantly altered by undergoing ACLS training, and it highlights a need for dedicated contrast reaction management courses.

In addition to simulating contrast reactions of various levels of severity, our study included testing and simulating a contrast reaction mimic (a hypoglycemic event). We found that participants reported a significant increase in comfort level after the simulation in their ability to differentiate contrast reactions from mimics. Most studies evaluating contrast reaction simulation have focused solely on contrast-related events that do not involve mimics [5,9-11,19]. This ability has important clinical significance, especially in diagnostic radiology departments, in which patients have various underlying medical conditions; being able to discriminate a true contrast reaction from an event that only mimics a contrast reaction can drastically alter treatments and outcomes.

Our study has several limitations. First, the examinations were distributed electronically and completed on an unmonitored basis. Although all participants were asked to complete the examination without using references, deviation from this protocol was not monitored or controlled. In addition, we assessed the effectiveness of training by analyzing test scores and reported comfort level instead of grading actions in reaction management, as has been done in other work [5,9,19].

Assessing management action events would have been difficult in our study population. Our simulation groups were a mixture of residents, fellows, and attending radiologists, to more closely reflect what occurs in response to a potential contrast reaction in our practice. However, this mixture can result in interaction bias, because more-senior faculty may be expected to take the lead. Another limitation is that we did not look at group dynamics, or ancillary staff training, which has been recently studied [15]. Finally, we did not alter any of the test questions between tests, so bias from recall of individual test questions is possible.

High-fidelity simulation is an effective learning tool, allowing practice in what would be high-acuity situations, but in a nonthreatening setting. Our study revealed a statistically significant improvement in overall test scores, as well as a marked increase in subjective comfort among participants in ability to manage contrast reactions of various severity levels, with a slight decline in scores noted at six months. This study supports use of high-fidelity simulation as a valuable teaching tool for contrast reaction management, for physicians in radiology across all levels of training and experience, and highlights the need for a refresher course at six months.

TAKE-HOME POINTS

- High-fidelity simulation is an effective learning tool in diagnostic radiology; it provides an opportunity to practice managing high-acuity situations in a nonthreatening environment.
- High-fidelity simulation significantly improves knowledge and subjective comfort in management of contrast reactions.
- Knowledge and overall subjective comfort in management of contrast reactions significantly declines at six months after a simulation training session, suggesting a need for biannual training.

ADDITIONAL RESOURCES

Additional resources can be found online at: http://dx.doi.org/10.1016/j.jacr.2015.08.016.

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