Original article

High-fidelity simulation training improves resident knowledge of contrast reaction management, especially for junior residents

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A B S T R A C T

Rationale and objectives: Contrast reactions are rare but serious events, frequently managed independently by Radiology Residents, who are likely underprepared to lead the acute event response. At our tertiary care center, Radiology Residents are the first responders to contrast reaction scenarios, and previously had didactic only training. We sought to create a High-Fidelity Simulation Training, and to assess whether this improved resident knowledge in managing contrast reactions.
Materials and methods: In September of 2020, we administered a didactic only contrast reaction training to 20 residents, with an anonymous 20 question multiple choice pre- and post-test. In January of 2022, we administered a 4-hour, 4-station contrast reaction High-Fidelity Simulation Training to 22 residents, with the same 20 question multiple choice pre- and post-test.
Results: The average number of residents answering each question correctly did not significantly improve following the didactic only training (p = 0.116). Following high-fidelity simulation training, however, there was a significant improvement by a mean of 2.45 (p = 0.028), as well as a mean improvement in individual scores of 10.45% (p = 0.0001). Comparing junior and senior residents, there was a significant difference in pre-test scores, with senior residents scoring on average 9.67% better (p = 0.0364); however on post-test scores, there was no significant difference.
Conclusion: High-fidelity simulation training improves resident knowledge of contrast reaction management, and allows inexperienced junior residents to attain senior resident level proficiency in these high-stress scenarios.

1. Introduction

Adverse events related to intravenous contrast administration for computed tomography (CT) scans and magnetic resonance imaging (MRI) are rare, but may have serious outcomes. The literature suggests that 0.6% and 0.01–0.22% of patients experience allergic-type reactions to iodinated contrast and gadolinium-based contrast, respectively [1,2]. Other adverse events such as contrast media extravasation occur more frequently, up to 1.2% [3]. At most institutions, radiologists are responsible for supervising the safe administration of contrast media and responding to adverse events. Unfortunately, the current literature suggests that many radiologists are unprepared to do so. For example, contrast reaction simulations reveal high error rates, up to 58%, in epinephrine administration for severe contrast allergic reactions [4,5].

At our tertiary care hospital and many academic institutions across

the country, radiology residents are first line responders to adverse events related to contrast media administration. Prior to 2020, hands on training to respond to these events at our institution was not formalized, and primarily occurred in the form of senior resident to junior resident on the job training, responding to events as they occur, although all residents were previously and continue to be advanced cardiovascular life support (ACLS) and basic life support (BLS) trained. Previously, one didactic lecture was given by a faculty member annually as part of the usual conference schedule. An anonymous survey of program directors at 51 programs across the country suggests a similar didactic approach to contrast reaction training- with 49% of programs reporting one didactic lecture annually, and only 18% reporting hands on simulation based training [6].

The literature has shown a significant improvement in both knowledge and comfort level in responding to contrast media adverse events

among radiologists when presented with high-fidelity simulation training [7–11]. Various strategies have been reported, with the most popular approach combining a didactic "pre-lecture" with simulation training to follow [8,12,13]. The simulations typically consist of mannequins or standardized patients with varying scenarios- most commonly moderate or severe contrast reactions, as these are most rare and life threatening [5,11,13]. Pre-test and post-test administration is also a popular approach to assess knowledge and identify areas for improvement. Additionally, in educational institutions with a dedicated Simulation Center, creating and running a high-fidelity simulation to prepare residents for contrast reaction management is relatively low cost, particularly when compared to the alternative of having untrained

physicians responding to emergencies [14].

Our aim was to create a high-fidelity simulation training course to prepare residents to adequately respond to contrast media adverse events, based on our review of the literature. Unfortunately, we began work on this project in February 2020, and when the worldwide pandemic hit in March of 2020, the Simulation Center at our institution was closed for about a year due to public health concerns. This afforded us the unique opportunity to create an intensive didactic contrast reaction response training, administered in September of 2020, followed by a didactic and high-fidelity simulation training, completed in January 2022, and to compare the two approaches. We hypothesized that the high-fidelity simulation training would improve resident's performance

1. Which of the following is considered an allergic like reaction to iodinated IV contrast administration?
a. Hypoglycemia
b. Flushing
c. Bronchospasm
d. Nausea

2. Which of the following is considered a physiologic-type reaction to IV contrast administration?
a. Erythema
b. Nasal congestion
c. Stridor
d. Vasovagal reaction

3. What is the estimated frequency of severe contrast reactions with low –osmolality IV iodinated contrast media?
a. 4%
b. 0.4%
c. 0.04%
d. 0.004%

4. What is the treatment of choice for urticaria as a reaction to contrast media?
a. Diphenhydramine
b. Fexofenadine
c. Either A or B
d. Epinephrine

5. What is the treatment of choice for a normotensive patient with diffuse erythema as a reaction to contrast media (in addition to monitoring vitals)?
a. Epinephrine
b. IV fluids
c. O2 by mask
d. Diphenhydramine

6. What is the pediatric dosing of IV epinephrine?
a. 1 mL/kg of 1:10,000 dilution
b. 0.1 mL/kg of 1:10,000 dilution
c. 1 mL/kg of 1:1,000 dilution
d. 0.1 mL/kg of 1:1,000 dilution

7. What is the adult IM dosing of epinephrine?
a. 0.1 mL of 1:1,000 dilution
b. 0.3 mL of 1:1,000 dilution
c. 0.1 mL of 1:10,000 dilution
d. 0.3 mL of 1: 10,000 dilution

Fig. 1. Pre-test and Post-test, correct answers in **bold.** This 20-question multiple choice was administered prior to and following the didactic and High-Fidelity Simulation trainings.

8. What is the appropriate management of Hypotension with a HR of 80 in an adult pt?
a. Elevate legs 60 degrees and give IV fluids
b. Administer Atropine IV
c. Administer Epinephrine IV
d. All of the above

9. You have an adult patient whose blood pressure is 80/40 and whose HR is 40 after receiving IV contrast. The patient is on a monitor, in Trendelenburg position, oxygen is being administered via a non-rebreather, and a code team/the ambulance has been called. What is the next best step?
a. Atropine IV slowly
b. Atropine IM
c. Epinephrine IV
d. Both a and c

10. You are called to evaluate an adult patient whose blood pressure has rapidly risen to 200/150, heart rate of 95 and a new headache. The patient is on the monitor, has oxygen, and rapid response team has been called. What next?
a. Start LR bolus
b. Administer labetalol IV
c. Administer Atropine IV
d. Administer Epinephrine IM

11. What is the most common reported severe injury after extravasation of contrast media?
a. Compartment syndrome
b. Delayed-type hypersensitivity reaction
c. Tissue necrosis
d. Allergic-type contrast reaction

12. When is surgical consultation indicated for contrast extravasation?
a. Progressive swelling or pain
b. Decreased capillary refill
c. Change in range of motion or sensation in affected limb
d. Skin ulceration or blistering
e. Any of the above
f. Only if extravasated contrast volume is greater than 100 cc

13. What is the treatment for contrast extravasation?
a. No known effective treatment
b. Warm compress
c. Cold compress
d. Attempted aspiration of extravasated contrast

14. Which of the following requires premedication prior to receiving iodinated contrast?

Fig. 1. (*continued*).

on the post-test multiple choice assessment tool that we created, particularly for first year residents who likely did not have first-hand exposure to contrast reactions.

2. Materials and methods

In September of 2020, we created a one-hour didactic lecture, including an interactive portion using Poll Everywhere (Deloitte Consulting) to incorporate contrast reaction scenarios. Prior to this lecture, the residents were instructed to read selected portions of the ACR Manual on Contrast Media 2020[15], as well as complete a 20 question multiple choice pre-test, based on information contained in the manual (Fig. 1). Residents were given 1 week to complete the pre-test.

Several of the questions in the multiple choice test were adapted from an educational exhibit presented by Asch et al. [16], and the remainder were written de novo. Following the didactic lecture, the contrast reaction kit at our institution was made available for residents to better familiarize themselves with the contents and practice drawing up medications. The 20 -question multiple choice post-test was administered after the session, with the same questions as in the pre-test. The post-test was administered as part of the session, at the end.

As the Simulation Center became available at our institution, we worked to create a High-Fidelity Simulation session for the residents to attend in January 2022. Prior to this session, 23 residents attended the same didactic lecture as administered in 2020, minus the Poll Everywhere scenarios, which were replaced by the High-Fidelity Simulation

a. Shell-fish allergy of urticaria

b. History of asthma

c. Prior iodinated contrast reaction of urticaria

d. All of the above

15. What is true regarding premedication for contrast reactions?

a. Patients with mild initial reactions are at high risk for moderate to severe breakthrough reactions.

b. There is no evidence to support a premedication duration of 2 hours or less

c. Physiologic reactions are also mitigated by premedication

d. All of the above

16. In a patient with acute bronchospasm after receiving IV contrast who is otherwise stable, what is the most appropriate initial treatment?

a**. Albuterol via inhalation 2-3 puffs or nebulizer**

b. IV Solu-Cortef

c. PO diphenhydramine

d. IV Epinephrine

17. You are called to evaluate a patient who complains of throat swelling. After placing the patient on a monitor and administering O2 by mask, the patient develops stridor and hypotension. What is the next appropriate step?

a. Epinephrine IM

b. Epinephrine IV

c. Albuterol via inhalation 2-3 puffs or nebulizer

d. PO diphenhydramine

18. How much Epinephrine can be administered for a contrast reaction?

a. Can repeat initial auto-injector dose every 5-15 minutes for 3 times

b. Can repeat IV dose every few minutes up to 1 mg total

c. Only one dose of Epinephrine may be administered

d. A and B

19. Which of the following scenarios require administration of Epinephrine?

a. Severe bronchospasm

b. Laryngeal Edema

c. Hypotension with tachycardia

d. All of the above

20. Which of the following is true about gadolinium contrast reactions?

a. Severe (life-threatening) reactions are more common than with iodinated contrast

b. There are no physiologic type reactions to gadolinium contrast

c. **Allergic like reactions to gadolinium contrast are similar to iodinated contrast medium reactions.**

d. All of the above

Fig. 1. (*continued*).

session. The same pre-test and post-test were administered. There were 14 residents who participated in the 2022 session who also participated in the 2020 session. The Simulation Session was scheduled for 4 h, with 4 different scenarios: a severe contrast allergy, a mild contrast allergy, a vasovagal reaction, and a contrast extravasation event (Table 1). The residents were divided into groups of 3 or 4, and each resident was instructed to "run" a simulation while their group members observed and provided feedback after the session. The two Interventional Radiology Fellows also joined in the simulation but did not complete the pre-test or post-test or attend the didactic session. The severe contrast allergy and mild contrast allergy scenarios were run with High-Fidelity Mannequins, and the vasovagal reaction and contrast extravasation event were run with Standardized Patients. Each simulation was supervised by a clinical instructor- either an Attending Radiologist or a Chief Resident, who also provided feedback to the residents. Two of the clinical instructors had participated in a two-day simulation training course at the simulation center and were involved with the simulation design. This training was specific to how to create a simulation, and thus all four instructors did not attend, however, all instructors participated in a mock ½ day simulation to work on individual scenario logistics and improve feedback techniques to the residents.

Pre-test and post-test results were collected anonymously in the

Table 1

Contrast Reaction scenarios used during the Simulation Sessions.

Scenario	Tech script	Initial exam	Treatment
Vasovagal Reaction	"The patient started to feel faint and lightheaded after the contrast injection"	- BP 80/50, HR 50 - No additional findings	- Perform Limited history and physical (H & P) - Administer O2 by NC - Place patient in reverse Trendelenburg - Administer 1 L NS - Consider treating nausea
Contrast Extravasation	"The contrast isn't showing up on the scan, and the patient's arm hurts! I injected about 50 cc before the patient started screaming"	- Normal vital signs - Extremity tenderness, swelling, erythema, paresthesia - Progress to complete numbness of fingers and change in range of motion	- Initially offer warm compress and arm elevation - Re-evaluate after 20 min and observe concerning exam - Call surgical consultation based on pain, numbness, and weakness concerning for compartment syndrome
Urticaria	"The patient is complaining of an itchy rash on their arm after getting contrast"	- Normal vital signs - Limited exam: urticarial	- Administer Diphenhydramine 25–50 mg or Fexofenadine 180 mg PO - Keep patient for 20–30 min to confirm improving prior to leaving. - Instruct patient not to drive and provide instructions for when to present to ER
Severe allergic type reaction	"The patient just got contrast and now they feel really sick! They say they can't breathe!"	- BP 60/40, O2 84%, HR 110, RR 20 - Stridor and erythema	- Recognize severe anaphylactic contrast reaction and call code blue - Administer O2 by NC or NRB - Administer Epinephrine at correct dose/route- IM 0.3 mL of 1:1000 dilution (autoinjector) preferred, alternatively IV 1 mL of 1:10,000 dilution - Start IV Fluids – 1 L bolus

didactic session of September 2020, with all 20 residents who participated completing the test. For the simulation session performed in January 2022, residents reported their name on their pre- and post-tests, allowing analysis of the results by year of resident. All 23 residents who participated completed the test, but one resident completed both the pre-test and post-test after the simulation session, and therefore was excluded from the results. There were 7 PGY-2/R1 residents, 5 PGY-3/R2 residents, 5 PGY-4/R3 residents and 5 PGY-5/R4 who completed the pre-test and post-test at the instructed time points (Fig. 2).

Following testing, the results were reviewed, and two questions were found to be poorly worded with two possible correct answers, and therefore both of these answers were accepted (see question #5 and 17, Fig. 1). Paired t-tests were used to compare pre- and post-test results for the didactic session as well as the simulation session, and unpaired t-tests were used to compare pre- and post-test results between junior (PGY-2/R-1 and PGY-3/R-2) and senior (PGY-4/R-3 and PGY-5/R-4) residents.

According to the policy defining activities which constitute research at our institution, this work met criteria for operational improvement activities exempt from IRB review.

3. Results

Didactic only contrast reaction training was administered in September of 2020, with pre-test and post-test results recorded for 20 residents. The average number of residents answering each question
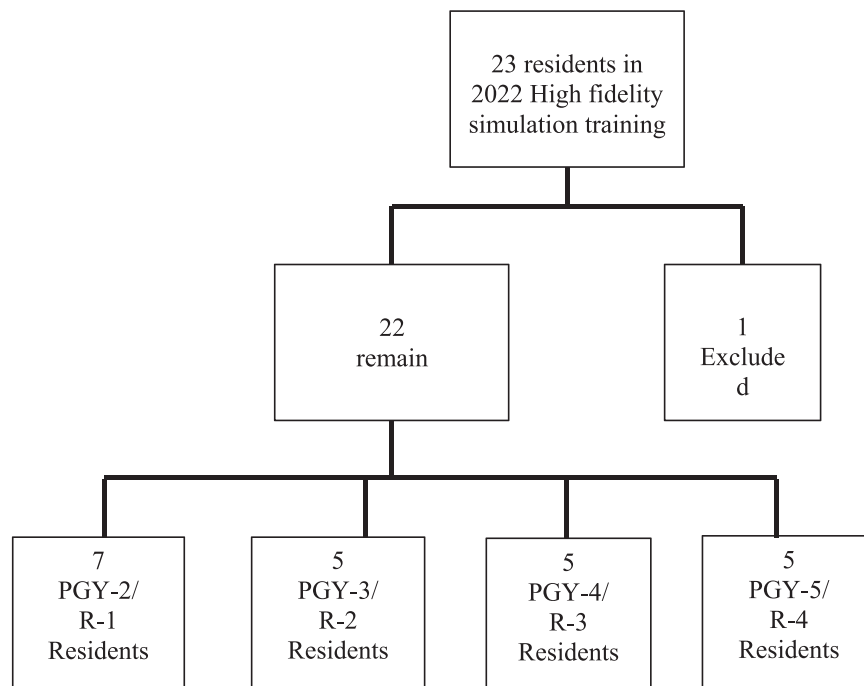

Fig. 2. Break down of residents participating in 2022 high fidelity contrast reaction simulation. All residents completed 4 h of training.

correctly on the pre-test was 13.5, and on the posttest was 15.4, how-ever, this increase was not significant (p = 0.116, Table 2). In January of 2022, high-fidelity simulation training for contrast reactions was completed, with 22 residents completing the pre- and post-tests in a timely manner. The average number of residents answering each ques-tion correctly on the pre-test was 14.84, and on the post-test was 17.30, with a mean improvement of 2.45, a significant improvement (p = 0.028, Table 2).

Overall, individual test scores also improved in the simulation group, with a mean score improvement of 10.45% (p = 0.0001, Table 3). When broken down by year of resident, test score improvement was significant only for PGY-2/R-1 and PGY-3/R-2 residents- with a mean improvement of 15% and 12%, respectively (p = 0.002 and 0.004, Table 3). Comparing junior (PGY-2/R-1 and PGY-3/R-2) and senior (PGY-4/R-3 and PGY-5/R-4) residents, there was a significant difference in pre-test scores, with senior residents scoring on average 9.67% better (p = 0.0364), however on post-test scores, there was no significant difference (Table 4).

4. Discussion

At our institution, and many similar academic institutions in the country, radiologists, specifically radiology residents are responsible for initial response to contrast reactions. It is also a required component of an ACGME accredited diagnostic radiology residency to provide training on and demonstrate competency in management of contrast reaction scenarios [17]. Prior studies have shown that radiologists, including attending and fellow radiologists, may be underprepared to manage such scenarios, particularly when epinephrine administration is required[2,4,5]. In recent years, as many medical schools and residency training programs have obtained simulation centers, contrast reaction simulations have been created to allow trainees to practice not only the theoretical knowledge needed to manage an adverse reaction but also the practical hands-on skills required[7,8,10,18]. Similarly, our pro-gram sought to improve our contrast reaction preparedness training by creating such a simulation. The delay in implementing the simulation due to the COVID-19 pandemic allowed us the opportunity to compare results between didactic and simulation-based training.

Didactic-based training did not significantly increase the average number of residents answering each question correctly on the pre- and post-test, however the simulation training did increase these numbers, as well as overall test scores. Many similar studies in the literature did not find a significant difference between their didactic and simulation-based training results [19,20]. However, not many programs had the opportunity to compare didactic and simulation-based training, and studies of simulation based training alone showed significant improve-ment, [7,8], consistent with our results.

Another interesting outcome of our simulation training is that it significantly improved the test scores of only our junior (R-1 and R-2) residents, with no significant change in the more senior residents. In contrast, in a similar study, Pfeifer et al. found significant improvement in all years of residents, but not in fellows or in faculty with 6–15 years of experience[10]. We postulate that this can be explained by

Table 3
High-Fidelity Simulation Mean Pre-test and Post-test scores broken down by Resident Year.

	Pre- test Mean % (SD)	Post -test Mean % (SD)	Difference (95% CI)	P value
PGY-2/ R-1	67.14 (6.99)	82.14 (6.99)	15 (7.94–22.06)	0.002*
PGY-3/ R-2	70.00 (10.61)	82.00 (13.04)	12 (6.45–17.55)	0.004*
PGY-4/ R-3	79.00 (10.84)	83.00 (9.08)	4 (−1.19 to 9.19)	0.099
PGY-5/ R-4	77.00 (13.96)	86.00 (8.94)	9 (−2.11 to 20.11)	0.088
Overall	72.73 (10.99)	83.18 (8.94)	10.45 (7.11–13.8)	0.0001

* p < 0.05 = significant

experience, or lack thereof, with managing contrast reactions in daily practice. At our institution, independent call begins in the R-2 year, so that by the R-3 and R-4 years, residents are likely to have managed at least 1 contrast reaction scenario independently, whereas R-1 and R-2 residents are less likely to have done so. Our contrast reaction simulation appears to have "leveled the playing field," as evidenced by the pre- and post-test scores. Senior residents scored better on the pretest, but not on the posttest in our sample, suggesting that a junior resident may attain senior level contrast reaction management knowledge through this simulation training. The difference in our results with those of Pfeifer et al. may be explained by the fact that our institution has no 24/7 in house attending coverage, unlike their institution, and therefore our senior residents are more likely to have independently managed a contrast reaction scenario.

Our study was somewhat limited by the non-randomized nature of the didactic vs. simulation training, and the small sample size in each cohort. It was also limited in that a different group of residents partic-ipated in the didactic only training as compared to the simulation only training, which may account for some of the difference in results, although there was an overlap of 14 residents between the groups. Additionally, the differences between the didactic and simulation groups may have been explained in part by the timing of the adminis-tration of the trainings- September is earlier in the academic year than January, and therefore first year residents would have less comfort/ experience with contrast reactions. The objective nature of the multiple-choice style testing is a strength, however we did not validate the questions prior to use, nor did we subjectively assess performance on the simulation portion, or administer a Likert-scale questionnaire pre- and post- simulation training to assess for improvement in resident confi-dence in managing simulations. These could be directions for future study. We could also seek to quantify the number of reactions that res-idents respond to each year, and correlate real-life experience with performance on pre- and post testing, as well as in the simulation. An interesting future study could be retrospective review of contrast reac-tion management in real- life scenarios prior to and following the administration of our simulation training. This would also help us to measure the clinical impact of our efforts, which we hope is to improve patient outcomes with better trained resident physicians responding to contrast reactions.

Overall, our contrast reaction simulation was felt to be very suc-cessful at improving resident competency in managing these low-frequency but high-acuity scenarios. Future directions for improving our training includes incorporating more scenarios, including a pediatric scenario, as well as develop a training that includes nursing and CT technologist staff. We would also like to determine the optimal time interval for repeating training, and the optimal time of year to do so.

5. Conclusions

Our results, though somewhat limited by small sample size and non-

Table 2
Number of participants answering each question correctly, by pre- and post- test, Didactic vs. High-Fidelity Simulation.

	Mean pre-test (SD)	Mean post-test (SD)	Mean improvement (95% CI)	Paired t Test P value*
Didactic only	13.5 (5.37)	15.4 (4.42)	1.9 (−0.51 to 4.31)	0.1160
High-Fidelity simulation	14.85 (5.07)	17.30 (3.60)	2.45 (0.29–4.61)	0.0280*

* p < 0.05 = significant

Table 4
High-Fidelity Simulation Comparison of Pre- and Post- test results by Junior and Senior Residents.

	Junior Residents (PGY-2,3/R-1,2) Mean % (SD)	Senior Residents (PGY-4,5/R-3,4) Mean % (SD)	Difference (95% CI)	Unpaired t-test P value
Pre-test	68.33 (8.35)	78.00 (11.83)	9.67 (0.68–18.66)	0.0364*
Post-test	81.25 (9.56)	84.50 (8.64)	3.25 (−4.93 to 11.43)	0.4172

* p < 0.05 = significant

randomization, suggest that simulation training improves resident knowledge of contrast reaction management, as measured by an objective multiple question examination, and allows inexperienced junior residents to attain senior resident level proficiency in these high-stress scenarios.

Ethical statement

According to the policy defining activities which constitute research at our institution, this work met criteria for operational improvement activities exempt from IRB review.

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CRediT authorship contribution statement

Danielle Kruse: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing - original draft. **Geoff Scriver:** Conceptualization, Methodology, Investigation, Writing - review & editing, Project administration. **Ryan Walsh:** Conceptualization, Methodology, Investigation, Writing - review & editing, Supervision, Project administration.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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