

# Prospective Analysis of an Interprofessional Team Training Program Using High-Fidelity Simulation of Contrast Reactions

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**OBJECTIVE.** Successful management of a contrast reaction requires prompt recognition and treatment and effective team dynamics among radiologists, technologists, and nurses. A radiology department implemented a simulation program in which teams of nurses, technologists, and physicians managed simulated contrast reactions. The purpose of this study was to evaluate whether simulation improved the participants' abilities to manage a contrast reaction and work in a team during an emergency.

**SUBJECTS AND METHODS.** Physicians, nurses, and technologists worked in interprofessional teams to manage two high-fidelity simulated adverse contrast reactions. Participants completed surveys before and after the simulation that included knowledge-based questions about the appropriate management of contrast reactions. Surveys also included questions for assessing participants' perceptions of their ability to manage adverse contrast reactions, measured with a 6-point Likert scale. Before and after comparisons were made with the McNemar test with a Bonferroni correction requiring  $p \leq 0.003$  for significance. For the other analyses,  $p \leq 0.05$  was considered significant.

**RESULTS.** After completion of the simulation exercises, participants had significant improvement in knowledge ( $p < 0.001$ ). After the simulation, participants reported significant improvement in their ability to manage an anaphylactoid reaction and their ability to work in a team ( $p < 0.00001$ ). Participants requested repeat simulation exercises every 6–12 months.

**CONCLUSION.** Simulation exercises improved the self-reported ability of radiology personnel to manage contrast reactions and work in a team during an emergency. Simulation should be incorporated into future educational initiatives to improve patient safety in radiology practices.

**S**imulation-based education and competency assessment have become increasingly integrated across multiple clinical disciplines, including anesthesiology, surgery, emergency medicine, obstetrics, and neonatology [1–6]. Meanwhile, efforts to improve patient safety and health care quality have emphasized the importance of communication and team training in medicine. The landmark Institute of Medicine report *To Err Is Human: Building a Safer Health System* [7] stated that health care organizations should establish team training programs for personnel that include proven methods such as those used in aviation, including simulation. In the clinical setting, team training simulation programs involving interprofessional operating room teams have documented improved communication and teamwork dynamics with evidence of an associated decrease in operative mortality [8–12].

Although radiology has been slower to adopt such an approach to simulation, previous studies in the radiology literature have shown the effectiveness of simulation-based training for radiology residents in the management of contrast reactions and radiologic emergencies [13–17]. A single previous study in which the participants were 24 radiology residents [18] showed incremental improvement in the utilization of team training skills after simulation. To date, simulation programs in radiology have focused on resident education. To our knowledge, only one study [15] has evaluated simulation-based training for radiologic technologists. Also to our knowledge, no studies in the radiology literature to date have addressed simulation-based training of attending radiologists, radiology fellow physicians, or radiology nurses, and no studies have been published on interprofessional team training simulation programs in radiology. We developed and implement-

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ed a high-fidelity mannequin simulation program to emphasize team training skills in the management of an adverse contrast reaction, and all physicians, radiologic technologists, and radiology nurses in our large university-affiliated radiology department were invited to participate. This prospective study sought to determine whether simulation improved participants' abilities to manage a severe contrast reaction and to work as a team during a medical emergency.

### Subjects and Methods

This prospective HIPAA-compliant study was undertaken after institutional review board exemption.

#### *Simulation Case Development and Implementation*

The department of radiology at a large medical school-affiliated hospital developed and implemented a simulation curriculum for contrast and emergency management with an emphasis on team training. Two simulated cases of anaphylactoid reactions to contrast media were developed in conjunction with collaborators from the departments of anesthesia, critical care, pain medicine, and emergency medicine (Appendix 1).

Before participation in simulation exercises, the participants completed didactic instruction [19]. For each 2-hour simulation session, eight participants were scheduled at the simulation laboratory on the hospital campus. All simulation sessions were conducted by one or two of three course facilitators from the department of radiology who had previously undergone dedicated simulation instructor training through the Center for Medical Simulation. On arrival, participants completed a presimulation survey. Participants were then oriented to the capabilities of the high-fidelity mannequin (SimMan 3G, Laerdal Medical) and the learning objectives for the simulation session, which included team training, medical knowledge, and patient care objectives. After orientation, the facilitator divided each group of eight participants into two teams, ensuring that physicians and technologists were represented on each team. A nurse was randomly assigned to a subset of teams.

For each simulation case, the mannequin's voice, vital signs, and behavior were dynamically controlled by a single operator located behind a one-way mirror under the supervision of one of the faculty facilitators. In addition to the team members participating in the simulated case, a confederate CT technologist functioned as an actor in each simulation case to assist team members as necessary. While the first team participated in the first simulation case, the second team observed from an adjacent room via live stream-

ing video. The teams were reversed for the second simulation case, which followed the first case debriefing. On completion of each case, a facilitated debriefing engaged members of both teams for feedback. Immediately after the second case and debriefing, participants were asked to complete the postsimulation survey before exiting the simulation laboratory.

#### *Study Participants*

All physicians, nurses, physician assistants, and technologists in the department who were involved in IV contrast administration were invited to participate in the simulation exercises and complete the before and after surveys. At our institution, approximately 450 departmental personnel were invited via e-mail to participate in the simulation exercises during the first year of the program (October 2012 through July 2013). Participants included attending physicians, fellow physicians, resident physicians, nurses, CT technologists, MRI technologists, interventional radiologic technologists, and other personnel, such as research assistants involved in contrast administration. Participants were excused from clinical responsibilities to attend, and the departmental leaders expected attendance from all departmental personnel involved in contrast administration, including personnel at satellite imaging centers.

#### *Structured Survey Instruments*

Presimulation and postsimulation survey instruments were adapted from surveys previously published [19]. Briefly, knowledge-based questions were multiple choice, and questions interrogating a respondent's self-reported comfort level were scored on the following 6-point Likert scale: strongly disagree, disagree, somewhat disagree, somewhat agree, agree, strongly agree. The questions on the postsimulation survey were identical to those on the presimulation survey and also included questions on the participant evaluation of the simulation program. For example, the postsimulation survey stated, "I would recommend that the contrast and emergency management simulation module be administered at the following frequency." Response options for this additional question included the following: once per person without need for repeat simulation exercises; once per person every 6 months; once per person every 12 months; once per person every 2 years; or other, please specify, which allowed free text entry. Each respondent entered a unique identifier to allow the presimulation and postsimulation surveys to be linked to each individual. To optimize response rate, both surveys were expected to be completed on a department-provided computer while the participant was in the simulation laboratory.

#### *Team Performance During Simulation*

Immediately after each simulation case, the CT technologist who participated in every simulation exercise as a confederate actor documented objective measures of team performance using a computerized, standardized survey instrument with dropdown menus.

#### *Statistical Analysis*

Data were compiled from respondents who completed both presimulation and postsimulation surveys, so data were linked for each individual. The McNemar test was used to compare proportions from these paired data. Bonferroni correction for multiple comparisons was applied to the  $p$  values in Table 1. A value of  $p \leq 0.003$  was considered significant. For the other statistical analyses,  $p \leq 0.05$  was considered significant. Paired  $t$  tests were used to compare the mean number of correctly answered knowledge-based questions before and after simulation, stratified by role group. The presimulation and postsimulation mean knowledge scores of attending physicians and resident and fellow physicians were compared by  $t$  test. Participants' correctly answered knowledge-based questions and self-reported comfort levels before and after simulation were compared by Spearman rank correlation coefficients. To assess whether different role groups requested different frequencies of future simulation exercises, a chi-square test was used.

## Results

### *Participants*

During the study period, our department consisted of 446 radiology personnel who were expected to treat a patient experiencing an adverse contrast reaction, including 115 attending physicians, 93 resident and fellow physicians, 40 nurses or physician assistants, 192 technologists, and six others, such as research assistants. All were invited to participate in the simulation exercises. Of the 446 individuals invited to participate, 369 (83%) attended and completed the simulation cases, including 110 of the 115 (96%) of the attending physicians, 74 of the 93 (80%) resident and fellow physicians, 26 of the 40 (65%) nurses or physician assistants, 159 of the 192 (83%) technologists, and all six of the others, such as research assistants. Of the 369 individuals who attended, 303 completed both the presimulation and postsimulation questionnaires, for a response rate of 82%. Participants who did not complete both questionnaires were excluded from analyses. Among the 303 participants who did complete both questionnaires, 96 (32%) were attending physicians, 60 (20%) were resident

**TABLE 1: Self-Reported Abilities of Radiology Personnel Before and After Completion of Simulation Exercises**

| Question                                                                                                                                   | Before Simulation        |                              | After Simulation         |                              | <i>p</i> <sup>c</sup> |
|--------------------------------------------------------------------------------------------------------------------------------------------|--------------------------|------------------------------|--------------------------|------------------------------|-----------------------|
|                                                                                                                                            | Comfortable <sup>a</sup> | Not Comfortable <sup>b</sup> | Comfortable <sup>a</sup> | Not Comfortable <sup>b</sup> |                       |
| How comfortable do you feel treating a patient with an anaphylactoid reaction to contrast media?                                           |                          |                              |                          |                              |                       |
| Physicians                                                                                                                                 | 110 (73)                 | 40 (27)                      | 144 (96)                 | 6 (4)                        | < 0.00001             |
| Resident and fellow physicians                                                                                                             | 48 (80)                  | 12 (20)                      | 59 (98)                  | 1 (2)                        |                       |
| Attending physicians                                                                                                                       | 62 (69)                  | 28 (31)                      | 85 (94)                  | 5 (6)                        |                       |
| Nurses                                                                                                                                     | 17 (81)                  | 4 (19)                       | 20 (95)                  | 1 (5)                        | 0.25                  |
| Technologists                                                                                                                              | 72 (61)                  | 47 (39)                      | 109 (92)                 | 10 (8)                       | < 0.00001             |
| Other                                                                                                                                      | 2 (40)                   | 3 (60)                       | 3 (60)                   | 2 (40)                       |                       |
| Total ( <i>n</i> = 295)                                                                                                                    | 201 (68)                 | 94 (32)                      | 276 (94)                 | 19 (6)                       | < 0.00001             |
| How comfortable do you feel working in a team during a medical emergency?                                                                  |                          |                              |                          |                              |                       |
| Physicians                                                                                                                                 | 135 (90)                 | 15 (10)                      | 145 (97)                 | 5 (3)                        | 0.003                 |
| Resident and fellow physicians                                                                                                             | 55 (92)                  | 5 (8)                        | 58 (97)                  | 2 (3)                        |                       |
| Attending physicians                                                                                                                       | 80 (89)                  | 10 (11)                      | 87 (97)                  | 3 (3)                        |                       |
| Nurses                                                                                                                                     | 19 (90)                  | 2 (10)                       | 21 (100)                 | 0 (0)                        | 0.5                   |
| Technologists                                                                                                                              | 94 (80)                  | 23 (20)                      | 114 (97)                 | 3 (3)                        | < 0.00001             |
| Other                                                                                                                                      | 3 (60)                   | 2 (40)                       | 5 (100)                  | 0 (0)                        | NA                    |
| Total ( <i>n</i> = 293)                                                                                                                    | 251 (86)                 | 42 (14)                      | 285 (97)                 | 8 (3)                        | < 0.00001             |
| How familiar are you with the equipment available in the contrast reaction treatment kits?                                                 |                          |                              |                          |                              |                       |
| Physicians                                                                                                                                 | 123 (82)                 | 27 (18)                      | 147 (98)                 | 3 (2)                        | < 0.00001             |
| Resident and fellow physicians                                                                                                             | 52 (87)                  | 8 (13)                       | 58 (97)                  | 2 (3)                        |                       |
| Attending physicians                                                                                                                       | 71 (79)                  | 19 (21)                      | 89 (99)                  | 1 (1)                        |                       |
| Nurses                                                                                                                                     | 14 (67)                  | 7 (33)                       | 21 (100)                 | 0 (0)                        | 0.016                 |
| Technologists                                                                                                                              | 91 (76)                  | 28 (24)                      | 119 (100)                | 0 (0)                        | < 0.00001             |
| Other                                                                                                                                      | 2 (40)                   | 3 (60)                       | 4 (80)                   | 1 (20)                       | NA                    |
| Total ( <i>n</i> = 295)                                                                                                                    | 230 (78)                 | 65 (22)                      | 291 (99)                 | 4 (1)                        | < 0.00001             |
| How comfortable do you feel administering intramuscular epinephrine to an adult patient with a contrast-induced anaphylactoid reaction?    |                          |                              |                          |                              |                       |
| Physicians ( <i>n</i> = 143)                                                                                                               | 117 (82)                 | 26 (18)                      | 142 (99)                 | 1 (1)                        | < 0.00001             |
| Resident and fellow physicians                                                                                                             | 41 (82)                  | 9 (18)                       | 50 (100)                 | 0 (0)                        | 0.004                 |
| Attending physicians                                                                                                                       | 76 (82)                  | 17 (18)                      | 92 (99)                  | 1 (1)                        | 0.00003               |
| How comfortable do you feel administering intramuscular epinephrine to a pediatric patient with a contrast-induced anaphylactoid reaction? |                          |                              |                          |                              |                       |
| Physicians ( <i>n</i> = 143)                                                                                                               | 79 (55)                  | 64 (45)                      | 122 (85)                 | 21 (15)                      | < 0.00001             |
| Resident and fellow physicians                                                                                                             | 28 (56)                  | 22 (44)                      | 43 (86)                  | 7 (14)                       | 0.00006               |
| Attending physicians                                                                                                                       | 51 (55)                  | 42 (45)                      | 79 (85)                  | 14 (15)                      | < 0.00001             |

Note—Values are numbers of respondents with percentages in parentheses. Total *n* may be different for each question because some respondents may not have answered one or more questions. NA = not available because McNemar tests were not performed because of extremely small sample size.

<sup>a</sup>Likert scale selection of very comfortable, comfortable, or somewhat comfortable.

<sup>b</sup>Likert scale selection of not at all comfortable, not comfortable, or somewhat uncomfortable.

<sup>c</sup>McNemar tests evaluating the proportion of participants who reported feeling comfortable and uncomfortable before and after simulation. Calculated *p* values were corrected for the problem of multiple comparisons by use of the Bonferroni method with *p* ≤ 0.003 considered significant.

and fellow physicians, 21 (7%) were nurses or physician assistants, 120 were (40%) technologists, and six (2%) were other personnel, such as research assistants.

#### Knowledge Improvement After Simulation

After completion of the simulation exercises, participants had a statistically significant 19% improvement in the mean num-

ber of correctly answered knowledge-based questions (*p* < 0.00001, paired *t* test). Stratified by role group, each role group had a statistically significant improvement in the

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mean number of correctly answered knowledge-based questions after simulation ( $p < 0.01$ , paired  $t$  tests, for attending physicians, residents and fellows, nurses, and technologists) (Fig. 1). Before simulation, no significant difference was identified in the mean knowledge scores of attending physicians compared with resident and fellow physicians ( $p = 0.37$ ,  $t$  test). After simulation, resident and fellow physicians had a higher mean knowledge score than attending physicians ( $p = 0.018$ ,  $t$  test).

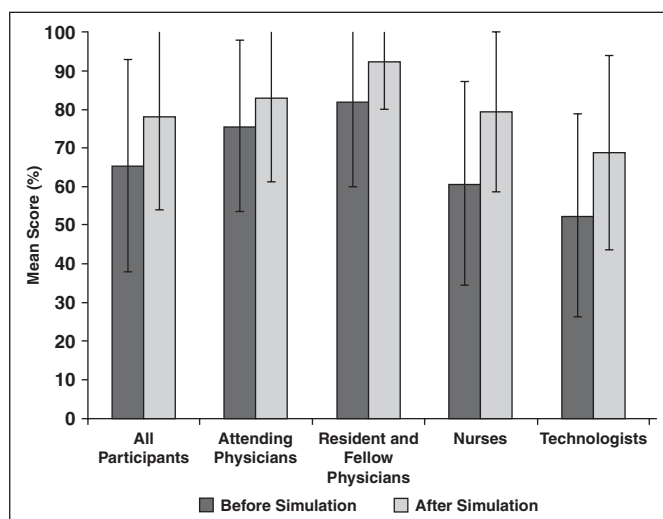
Before simulation, 247 of the 303 participants (82%), including 77 of the 96 (80%) attending physicians, 56 of the 60 (93%) resident and fellow physicians, 16 of the 21 (76%) nurses or physician assistants, 96 of the 120 (80%) technologists, and two of the six (33%) others correctly identified epinephrine as the treatment of choice of a moderate to severe anaphylactoid reaction to contrast medium. No statistically significant improvement was identified after simulation for all participants or stratified by individual role group. After the simulation, all respondents had statistically significant improvement in identifying the correct dose of intramuscular epinephrine, especially physicians and technologists (all participants  $p < 0.001$ ; physicians,  $p = 0.001$ ; technologists,  $p < 0.001$ ; nurses,  $p = 0.18$ ). After simulation, respondents had statistically significant improvement in identifying the correct concentration of intramuscular epinephrine (all participants,  $p = 0.03$ ).

After simulation, knowledge of the appropriate dose of IV epinephrine significantly improved for each role group (all participants,  $p < 0.001$ ; physicians,  $p < 0.001$ ; nurses,  $p = 0.015$ ; technologists,  $p < 0.001$ ). After simulation, knowledge of the appropriate concentration of IV epinephrine significantly improved for all respondents, in particular for technologists (all participants,  $p = 0.0001$ ; physicians,  $p = 0.38$ ; nurses,  $p = 1.0$ ; and technologists,  $p < 0.001$ ).

### Self-Reported Ability to Work Effectively as a Team to Manage a Contrast Reaction

All respondents reported improvement in their ability to manage an anaphylactoid reaction after simulation ( $p < 0.00001$ ) (Table 1). In particular, physicians and technologists reported statistically significant improvements in comfort levels managing an anaphylactoid reaction ( $p < 0.00001$ ). After simulation, all respondents had statistically significant improvement in familiarity with

**Fig. 1**—Bar graph shows mean scores for knowledge-based questions before and after simulation. Whiskers indicate 1 SD.



the departmental standardized contrast reaction kits ( $p < 0.00001$ ). After simulation, participants reported statistically significant improvement in their ability to work as a team ( $p < 0.001$ ). Stratified by role group, physicians ( $p = 0.003$ ) and technologists ( $p < 0.00001$ ) had statistically significant improvement in self-reported ability to work on a team after simulation. The small sample size of nurses may limit statistical power to assess interval improvement in this role group. In the presimulation and postsimulation surveys, physicians were asked to assess their ability to administer epinephrine. After simulation, physicians reported statistically significant improvement in their ability to administer epinephrine to an adult ( $p < 0.00001$ ) or a child ( $p < 0.00001$ ).

### Correlation of Knowledge Level With Self-Reported Comfort Level Before and After Simulation

Of the 295 respondents who self-reported presimulation and postsimulation comfort levels, 293 respondents answered all eight knowledge questions before and after simulation. Before simulation, there was no statistically significant correlation between higher knowledge scores and higher comfort levels working in teams, treating an anaphylactoid reaction, familiarity with the contrast reaction kit, or administering epinephrine to an adult or pediatric patient. After simulation, no significant correlations between knowledge and comfort levels were identified.

### Team Performance During Simulation

Of the 100 teams participating in simulation, objective measures of team perfor-

mance during the simulation exercises were completed for 87 teams. The 87 teams participated in 44 cases of bronchospasm and 43 cases of hypotension with tachycardia. During the simulation case 44% of teams explicitly assigned a team leader. Of the 95% of teams that called for help, 36% needed prompting. Of the 83 of 87 (95%) teams that administered intramuscular epinephrine, 64 (77%) teams correctly injected into the lateral thigh or arm, and 49 (59%) teams performed all necessary steps to correctly use the autoinjector. No team administered IV epinephrine in either case, although IV epinephrine was available in the simulation room crash cart. The crash cart provided in the simulation room was identical to those used throughout the institution and satellite imaging sites. For the 44 simulated cases of bronchospasm, oxygen was not administered in two (5%) cases. In the 43 simulated cases of hypotension with tachycardia, oxygen was not administered in six (14%) cases, and IV fluid resuscitation was not performed in three (7%) cases.

### Participant Feedback Regarding Simulation Exercises

After simulation, 299 of the 303 (99%) participants, including 89% of attending radiologists, agreed that the 2-hour simulation exercise was a high-yield use of their time. A large majority (97%) of participants believed that simulation should become integrated into the departmental educational curriculum on contrast reactions. Among all respondents, 75% preferred that departmental personnel undergo simulation exercises at least every 6–12 months, and 19% suggest-

ed that participants undergo simulation exercises every 2 years (Fig. 2). No significant differences were observed in the desired frequency of simulation exercises across role groups ( $p = 0.9$ ).

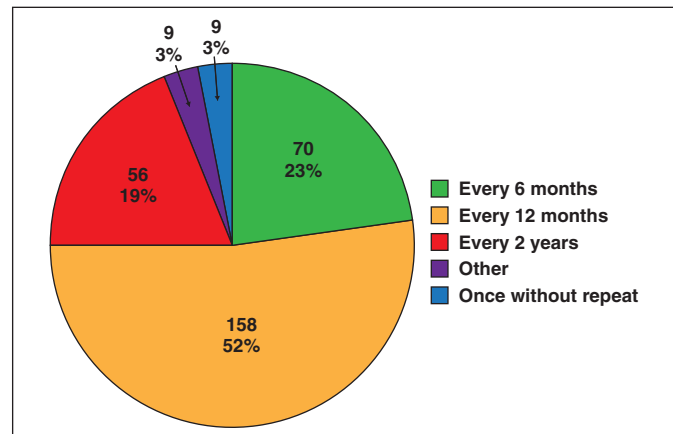
## Discussion

In this study, we sought to understand whether implementation of a simulation-based training program would affect two skill sets: participants' abilities to manage an adverse reaction to contrast medium and participants' abilities to function as effective team members. To our knowledge, our study is the first to investigate the effectiveness of a department-wide contrast and emergency management simulation program with an emphasis on team training for radiologists, radiology resident and fellow physicians, radiology technologists, and radiology nurses.

Simulation exercises allow participants to apply and improve their skills without compromising the safety of a real patient. Infrequent but high-stakes events, such as moderate or severe adverse reactions to contrast media, are ideally suited for simulation-based education [6, 20]. Results of several previous studies suggest that radiologists, resident physicians, nurses, and technologists could improve their knowledge regarding the appropriate management of contrast reactions, which is not surprising given the low frequency of moderate or severe contrast reactions [15, 21–24]. Simulation training in conjunction with didactic instruction statistically significantly improves radiology resident knowledge and comfort levels. Studies have shown up to 25% improvement in knowledge and 17% improvement in self-reported comfort in the management of contrast reactions [13–18]. Our study contributes additional data to this growing body of literature showing that simulation improves radiology resident and fellow physician knowledge and comfort levels over didactic instruction alone.

To date, the literature on simulation in radiology has focused on training resident physicians. Our findings suggest that other role groups in a radiology department would also benefit from simulation because our attending physicians and technologists also had improvements in knowledge and self-reported comfort levels after simulation. Our findings are consistent with those of a single previous study of contrast reaction simulation exercises in a nonresident role group [15], which included 11 technologists whose knowledge improved similarly to that of resident physi-

**Fig. 2**—Chart shows participants' requested frequency for future simulation exercises. Other includes free-text responses such as once every 5 years, once every 3 months, and once every 3 years.



cians after simulation. In clinical practice, the CT or MRI technologist is usually the first responder to an adverse contrast reaction, and the technologist then calls a nurse or physician for additional assistance when deemed necessary. Thus, an effective simulation-based training program for contrast reactions should include technologists, nurses, and attending physicians, rather than restricting participation to residents.

In addition to targeting improvement in the appropriate management of contrast reactions, our simulation-based training program included nurses, technologists, and physicians, so that our simulation exercises could emphasize team training skills. The simulation exercises allowed participants to practice the basic tenets of team training (e.g., closed-loop communication, speaking up or appropriate assertion, and team leadership during a crisis). Implementation of team training education was found to reduce surgical mortality 18% in a large multicenter study [11]. Simulation-based educational programs for team training have been adopted across clinical specialties, including anesthesiology, surgery, and obstetrics [9, 25–28].

Although studies on the effectiveness of team training simulation exercises in other specialties have focused on resident physicians, a 2014 multicenter simulation-based team training program for operative teams [28] showed that 93% of attending anesthesiologists, attending surgeons, and operating room nurses reported that the simulation exercises helped them provide safer patient care. To our knowledge, our study is the first to show similar findings within a radiology department. Technologists and attending radiologists reported statistically significant improvements in their abilities to work in teams. Furthermore, 99% of participants, including

89% of attending radiologists, believed that simulation was a high-yield use of their time.

Our results suggest that team-training simulation programs are as relevant to radiology as they are to other clinical departments. Beyond contrast reactions and other urgent medical events that occur in the general radiology suite, interventional radiology procedures, regardless of complexity, are prone to the same types of errors, including communication errors, associated with traditional operating rooms. Historically, procedural complications account for approximately one third of malpractice allegations against radiologists, second only to allegations of failure to diagnose [29]. Given the growth of image-guided interventions performed by radiologists, the need for training that emphasizes teamwork and communication has never been more urgent.

Our study had several limitations. Participants received identical surveys before and after the simulation, which may have allowed them to learn to the test. Although this could have artificially increased knowledge scores after simulation, we hypothesize that identical survey questions are less likely to be responsible for the statistically significant improvements in participants' self-reported abilities to manage a contrast reaction and work in a team during an emergency. The high response rate for surveys in our study likely minimized non-response bias [30]. Another limitation of our study was that it was single-institution experience, which may limit generalizability. Implementation of simulation exercises in other radiology practices may be hampered by a variety of factors, including a lack of space for simulation exercises, a paucity of experienced faculty to conduct the debriefings, and cost. In a previous study [31], however, investigators estimated that a high-fidelity simulation pro-

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gram for contrast reaction management costs approximately \$200 per radiology resident. The lack of clinical productivity for personnel while participating in simulation exercises represents another cost. Our simulation program excused radiology personnel from their clinical duties for 2 hours during a single work day. This time is abbreviated compared with the 4- to 8-hour, or even multiday, simulation programs that have been previously implemented and evaluated [11, 16, 18, 28].

Another limitation was that the skills evaluated in this study were measured immediately after the simulation exercises, and no attempt was made to measure retention. Another limitation was that the participants may not have taken the simulation seriously or may not have behaved in the way they would normally act. However, there was no indication from participants that they did not take the simulation seriously, and there is evidence that people's behaviors during simulation mirror their actual behaviors [32]. A final limitation was the lack of data regarding whether our simulation program improved patient outcomes in the management of contrast reactions or other radiologic emergencies in clinical practice. Because these events are infrequent, it will likely take years of data collection across multiple sites to understand whether simulation exercises involving radiology personnel resulted in improved patient outcomes. In the meantime, it seems reasonable to infer that simulation would improve patient safety and decrease mortality among patients with adverse events in radiology, just as it has in other clinical disciplines [11].

Successful training of radiology personnel in contrast and emergency management requires more than didactic instruction on the appropriate potency and delivery system for epinephrine. Performance gaps identified during simulation exercises for contrast and emergency management should be targeted for future educational initiatives to improve patient safety in clinical practice. Effective teamwork dynamics and communication must also be emphasized during training that targets contrast and emergency management. Our simulation program improved participants' self-reported abilities to manage a severe contrast reaction and work as a team during a medical emergency. As a result of these findings, our radiology department mandates annual simulation exercises for all personnel involved in contrast administration or procedures, including staff at satellite imaging centers. Future research on

simulation in radiology is needed to identify the optimal frequency and duration of simulation training, to create an adequate number and appropriate variety of case scenarios (including pediatric emergencies), and to understand how simulation exercises may improve patient outcomes.

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## APPENDIX I: Two Simulated Cases of Anaphylactoid Reactions to Contrast Media

### Case 1: Bronchospasm With Hypoxia

1. Describe the signs, symptoms, and severity of a bronchospasm reaction after intravascular iodinated contrast injection.
2. List the indications for epinephrine administration in the setting of bronchospasm.

**Scenario:** A 77-year-old man with a history of rectal carcinoma is scheduled for CT of the chest, abdomen, and pelvis to evaluate for recurrent disease. Several minutes after IV injection of iodinated contrast medium, the simulated patient reports shortness of breath. Auscultation by the team reveals wheezing.

**Presumed order of events:**

1. Team enters the room and begins interviewing the patient while collecting vital signs.
2. Vital signs include tachypnea (respiration rate, 26 breaths/minute) and hypoxemia (oxygen saturation, 90%). Team is expected to call for help promptly.
3. Team is expected to administer oxygen via nonrebreather mask at 6–10 L/min.
4. Given the patient's hypoxemia, the team is expected to administer epinephrine.
5. If team administers albuterol nebulizer, patient responds with minimal oxygen saturation increase ( $\approx 5\%$ ).

### Case 2: Hypotension With Tachycardia

1. Describe the signs, symptoms, and severity of an anaphylactoid reaction to contrast media that involves hypotension with tachycardia.
2. Demonstrate appropriate use of epinephrine when patient is unresponsive to fluid resuscitation.

**Scenario:** A 51-year-old man with a history of diverticulosis is undergoing CT of the abdomen and pelvis for left lower quadrant pain. Several minutes after completion of the IV iodinated contrast injection, the simulation patient reports not feeling well and having generalized itching.

**Presumed order of events:**

1. Team enters the room and begins interviewing the patient while collecting vital signs.
2. Mild tachycardia and hypotension prompt the team to administer IV fluids.
3. Patient becomes more unresponsive with worsening tachycardia and hypotension. Team should call for help promptly.
4. Team should assess appropriate need for epinephrine and administer epinephrine.