A Checklist Manifesto: Effectiveness of Checklist Use in Hands-On Simulation Examining Competency in Contrast Reaction Management in a Randomized Controlled Study

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OBJECTIVE. The purpose of this article is to assess the performance of a contrast reaction management checklist for optimal management of a contrast reaction scenario created using a high-fidelity hands-on simulation.

MATERIALS AND METHODS. A safety checklist was designed that presented the five adverse events that most commonly occur after administration of IV contrast medium as well as their step-by-step management. Forty-three radiology residents were randomized into two groups, a checklist group ($n = 22$) and a control group ($n = 21$), as stratified by postgraduate year. Participants took written tests involving multiple-choice questions 2 months before and immediately after participating in the high-fidelity simulation scenario, which was videotaped and independently evaluated by three graders.

RESULTS. Both groups had similar scores on the multiple-choice question tests taken before and after participation in the simulation ($p = 0.35$ and $p = 0.62$, respectively). In the simulation, the checklist group scored significantly higher than the control group with regard to their overall management of a severe contrast reaction (85.1% vs 64.8%; $p = 0.001$), including individual scores for first-line treatment of bronchospasm (97.0% vs 91.3%; $p = 0.035$) and use of the correct route of administration and dose of epinephrine (77.3% vs 45.2%; $p = 0.021$).

CONCLUSION. A standardized contrast reaction management checklist can reduce the number of treatment errors that occur during a simulated severe contrast reaction, particularly with regard to proper administration of epinephrine and treatment of bronchospasm. Such a checklist could be used by radiologists, technologists, and nurses to improve patient safety as a result of improved contrast reaction management and teamwork skills.

Keywords: checklist, contrast media, contrast reaction management, high-fidelity simulation

doi.org/10.2214/AJR.17.19384

Received December 6, 2017; accepted after revision January 21, 2018.

Based on a presentation at the Radiological Society of North America 2017 annual meeting, Chicago, IL.

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Supplemental Data
Available online at www.ajronline.org.

AJR 2018; 211:W1–W12

0361–803X/18/2111–W1

Preventable medical errors are the third leading cause of death in the United States [1–3]. In radiology, contrast reaction management is particularly prone to preventable error and often has life-threatening implications. It has been shown that radiology staff members often mismanage severe contrast reactions, regardless of their level of training [4, 5]. A study showed that, when managing a severe anaphylactic contrast reaction, 71% of survey respondents, including attending physicians, fellows, residents, and nurses, incorrectly identified the dose and rate of administration of IV epinephrine, and 48% incorrectly identified the dose of intramuscular epinephrine [6]. Fortunately, with modern contrast media, reactions are rare. Recent estimates of the rate of adverse reactions associated with administration of iodinated contrast media range from 1% to 12%, with severe reactions accounting for 0.01–0.2% of all adverse reactions [7–9]. However, because rates of moderate and severe contrast reactions are low, radiologists encounter such reactions infrequently and therefore are inexperienced and ill prepared to manage them [5, 10, 11]. Many residents may complete training without ever managing such events.

Another source of error in health care is intimidation by superiors, which often occurs as a result of an established or perceived hierarchy. Many instances of harmful errors in medication administration that affect patients share a common factor: at least one member of the health care team thought that something was wrong with the order before the medication was dispensed and administered but was too intimidated to voice concern [12].

Effective contrast reaction management relies on knowledge of a simple management algorithm based on correct identification of the type of reaction. Within each type of reaction, the algorithm specifies the type of required medication and the correct route of adminis-

tration and dose of that medication. Although only a few decision points exist, errors at any stage may be catastrophic. Given the known risks of preventable error compounded by inexperience with contrast reaction management, a checklist could be a useful tool to help simplify the management algorithm in a high-stress scenario. Several studies have shown the positive effect of safety checklists in health care, including effectiveness in decreasing central line–related infections and improved communication in ICUs [13–15]. However, some studies have suggested that the benefits of using safety checklists should be interpreted with caution, given the presence of bias in many of these studies [16].

We hypothesized that a contrast reaction management checklist would result in more optimal management of a contrast reaction scenario created using a high-fidelity hands-on simulation in a randomized controlled study to reduce mortality and morbidity. We also postulated that having a safety checklist might increase a resident's confidence to express concern and resolve conflict when his or her superior suggests an incorrect medication.

Materials and Methods

The present study was approved by the institutional review board at University of Washington School of Medicine and was HIPAA compliant. Participation was voluntary, and written informed consent was obtained from all participants.

Study Participants and Training Groups

At our institution, simulation-based training has been used as an effective substitute for real-life experience in assessing and providing training in contrast reaction management skills and improving behavior scores [17–22]. These simulations are a mandatory part of radiology residents' annual contrast reaction management training and include presimulation tests and postsimulation tests for residents' self-evaluation.

All residents at our institution attended a 1-hour didactic lecture about contrast reaction management 3–6 months before our intervention, as part of their categoric lectures. In addition, all residents attended an hour-long didactic lecture about teamwork skills before starting their radiology residency. This latter lecture included strategies for conflict resolution when identifying a safety issue with the use of TeamSTEPPS (Team Strategies & Tools to Enhance Performance & Patient Safety), an evidence-based method rooted in 3 decades of research by the Department of Defense Patient Safety Program in collaboration with the Agency for Healthcare Research and Quality [23]. In TeamSTEPPS, this skill is known by the acronym CUS. Residents learn to express concern regarding potential safety issues by saying key phrases such as "I am concerned," "I am uncomfortable," or "This is a safety issue" (with the three initial letters in the words "concerned," "uncomfortable," and "safety" forming the acronym CUS) [24].

All 46 residents in our radiology residency program were approached to participate in the study. Two residents did not participate. The remaining 44 residents were randomized and stratified by postgraduate year (PGY) into the checklist group ($n = 22$) and the control group ($n = 22$). Residents were not informed of their group assignment until the beginning of their simulation session. One resident assigned to the control group was excused from participating in the simulation because of a conflict with her call schedule. The final sample size in the checklist groups and the control group was 22 and 21 residents, respectively.

The Checklist

A safety checklist for contrast reaction management was developed based on the American College of Radiology Manual on Contrast Media [25] and our institutional policies. The checklist included key steps in initial patient evaluation, the five pertinent contrast reactions and their manifestations, a management algorithm for each reaction, and the key components for follow-up and debriefing. The safety checklist was color-coded to help link each type of contrast reaction with its corresponding management algorithm (Fig. 1).

Hands-On Simulation Examination

Each resident participant underwent a 30-minute examination session at the simulation laboratory. Before beginning the contrast reaction scenario, participants were given a 5-minute standardized orientation to the high-fidelity manikin (SimMan, Laerdal) and the room's facilities, including the location and contents of the contrast reaction box. The checklist group was provided with a laminated copy of the checklist and was given an extra 2 minutes to review it. This period was chosen to give them time to familiarize themselves with the form and how to use it but not enough time to memorize the algorithms.

A final test script of the standardized contrast reaction simulation scenario is presented in Appendix 1. To replicate a real contrast reaction scenario, participants were told to interact with the manikin as if it were a real patient, and they were required to perform any required intervention as if it were a real scenario, including speaking to the "patient," drawing up and administering medications, and providing a warning before performing the injection. Actions were required to be as specific as possible. For example, when administering medication, resident participants were asked to specify the route of administration, dose, and units and indicate whether a flush of the IV line was needed. The manikin displayed physiologic and physical changes in real time, on the basis of the participants' actions. Each high-fidelity simulation scenario was videotaped for the purposes of grading, self-reflection, and feedback to identify areas for improvement.

In addition to the standardized contrast reaction scenario, each simulation also included a confederate who suggested an improper medication to test the resident's conflict resolution skills [22]. During each session, the confederate, who played the role of a new attending physician, entered the room after the patient had symptoms of anaphylaxis develop and incorrectly instructed the resident to administer atropine. This tested the resident's ability to use CUS, an important communication skill for the prevention of medical errors in TeamSTEPPS.

Immediately after each simulation session, the instructor debriefed participants on both contrast reaction learning points (including code team activation, proper route of administration and dose of oxygen, correct management of vasovagal reaction, management of bronchospasm, management of upper airway edema, correct dosing of epinephrine via different routes of administration, and use of alternate routes of epinephrine administration if there is no IV access), and conflict resolution skills (including CUS and the two-challenge rule) to empower members to "stop the line" if they are concerned about a safety breach. Residents were instructed not to share the test questions or information regarding the scenario with the other residents.

Presimulation Tests and Postsimulation Tests

To establish resident knowledge and experience at baseline, participants completed a written multiple-choice question (MCQ) presimulation test and questionnaire 2 months before the simulation occurred. Immediately after the simulation session, an MCQ posttest and questionnaire were provided to the participants to measure improvement in their knowledge. Both written tests evaluated the same core concepts using 10 unique questions.

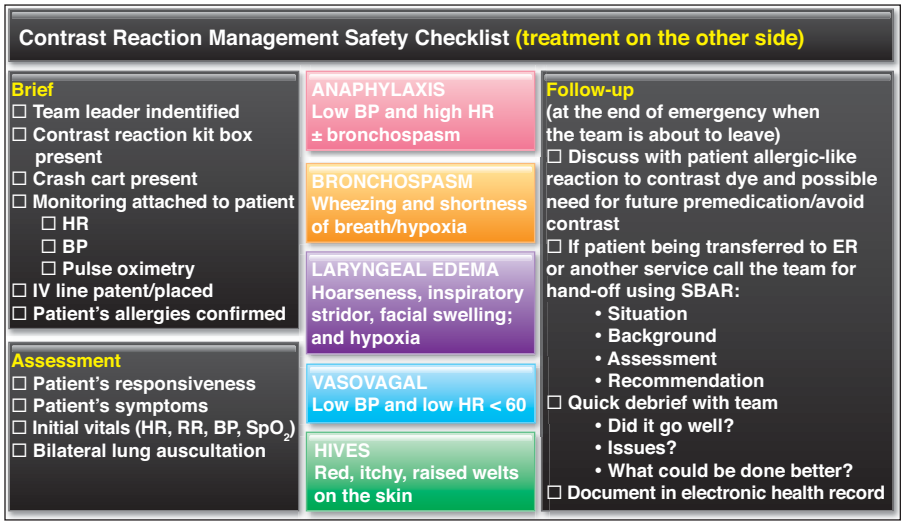
Grading Methods

Grading consisted of objective assessment of actions taken or not taken and overall subjective impressions of performance. The standardized grading sheets used by the graders are shown in Appendix 2 and were based on a previously used grading sheet [26]. The objective assessment was divided into four areas, including initial workup, first-line treatment, other treatments, and epineph-

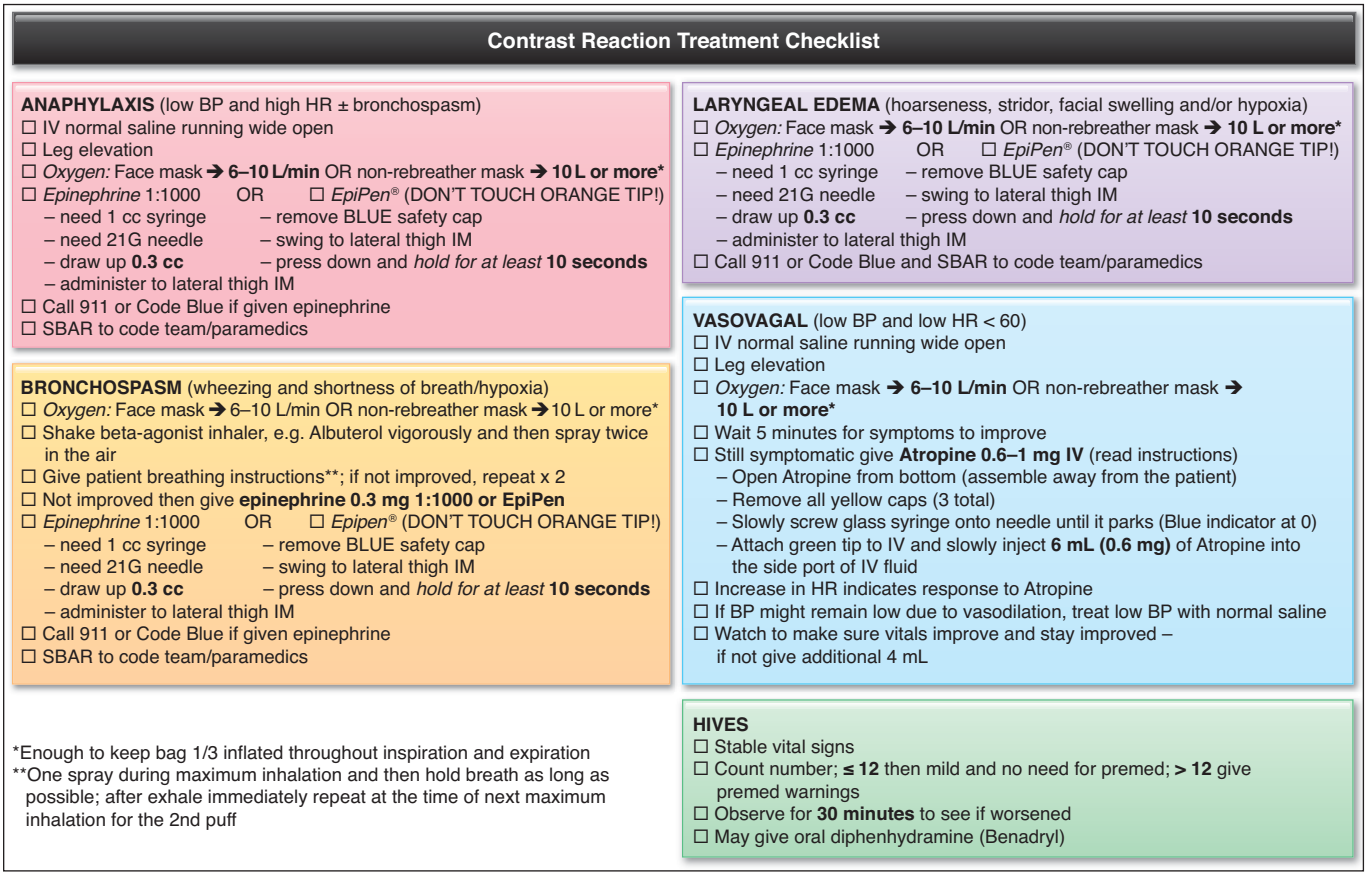
rine administration, in addition to the conflict resolution challenge. A 5-point Likert-like scale was used to rate subjective impressions regarding each resident's assessment of the patient, identification of the type of reaction, administration of medications, treatment of the reaction, CUS performance, use of the two-challenge rule, and overall performance.

The videos of five participants (three in the checklist group and two in the control group) were inadvertently lost because of camera malfunction on the day of simulation. For these participants, grading of the objective portion of the assessment was performed by one faculty member who was present, on the basis of her extensive and detailed notes recorded during the scenario. The subjective assessments of contrast reaction management performance were not completed for these five participants because they could not be ascertained from the grader's notes. For the other 38 participants, three contrast reaction experts with 5 years, 8 years, and more than 30 years of experience in-

Fig. 1—Color-coded safety checklist.
A and **B,** Checklist sections show types of contrast reactions (**A**) and their subsequent management (**B**). HR = heart rate; BP = blood pressure; RR = respiratory rate; SpO_2 = functional oxygen saturation; ER = emergency room; SBAR = situation, background, assessment, recommendation; IM = intramuscular; SC = subcutaneous.



A



B

TABLE 1: Change in Comfort Levels Noted Before and After Simulation Test in Checklist and Control Groups

Variable	Checklist Group ($n = 22$)			Control Group ($n = 21$)			Between-Group p[b]
	Before Test	After Test	Within-Group p[a]	Before Test	After Test	Within-Group p[a]	
Written test (%)	77.3 ± 13.9	86.8 ± 11.3	0.006[c]	80.5 ± 19.9	84.8 12.1	0.54	0.068
Questionnaire (%)[d]							
Comfortable managing reactions	2.7 ± 0.9	3.4 ± 0.8	0.004[c]	3.0 ± 1.1	3.8 ± 0.8	0.005[c]	0.75
Comfortable identifying reactions	3.6 ± 0.7	4.2 ± 0.7	0.006[c]	3.6 ± 0.9	4.3 ± 0.6	0.001[c]	0.84
Comfortable administering the medication	2.9 ± 0.8	3.7 ± 0.8	0.001[c]	3.0 ± 1.0	3.7 ± 1.0	0.013[c]	0.58
Comfortable administering the proper dose	2.7 ± 1.0	3.6 ± 0.7	0.001[c]	2.7 ± 1.1	3.7 ± 1.0	0.001[c]	0.97

Note—Except where otherwise specified, data are mean score (± SD).
[a]Wilcoxon signed rank test comparing the presimulation and postsimulation test scores.
[b]Wilcoxon rank-sum test comparing the changes in scores (postsimulation test scores minus presimulation test scores) between groups.
[c]Statistically significant.
[d]Five-point Likert-like scale (with 1 denoting strongly disagree and 5 denoting strongly agree).

dependently graded the videos. All graders had previously published studies on contrast reactions. Graders were also trained by the teamwork skills expert, who completed the master trainer TeamSTEPPS program. With regard to the objective assessment, any discrepancies between graders were adjudicated by a fourth grader after review of the corresponding videos.

From the objective assessment, each participant received a subscore that corresponded to each area (initial workup, first-line treatment, other treatments, and epinephrine administration) and was calculated as a percentage of total points received from the total points possible. A total contrast reaction management score was then calculated for each participant as the weighted average of each contrast reaction management subscore. The weights for each of the four items were 10%, 30%, 10%, and 50%, respectively [26].

Data Analysis

Before the study was conducted, a power analysis was performed to determine feasibility and the number of residents to approach for enrollment. On the basis of our previous experience [26], for calculations of sample size, we assumed an SD of 15% for the total objective contrast reaction management score. Under this assumption, and with 22 participants randomized to each group, we would have 90% power to detect a significant difference between groups if the true difference was 15%, which was considered plausible.

Continuous variables were summarized as the mean value (± SD), and categoric variables were calculated as the count (percentage). The primary endpoint was comparison of the total objective contrast reaction management score between the checklist group and control group, as determined using the Wilcoxon rank-sum test. The Wilcoxon rank-sum test was also used to compare the objective subscores, the objective conflict resolution score, subjective scores, MCQ test scores, and questionnaire responses between groups. Changes between presimulation and postsimulation MCQ tests and questionnaire responses were assessed using the Wilcoxon signed rank test. Resident experience at baseline was compared between groups using the Fisher exact test. The Spearman rank correlation coefficient was used to evaluate relationships between the total contrast reaction management score, the MCQ test score, and PGY.

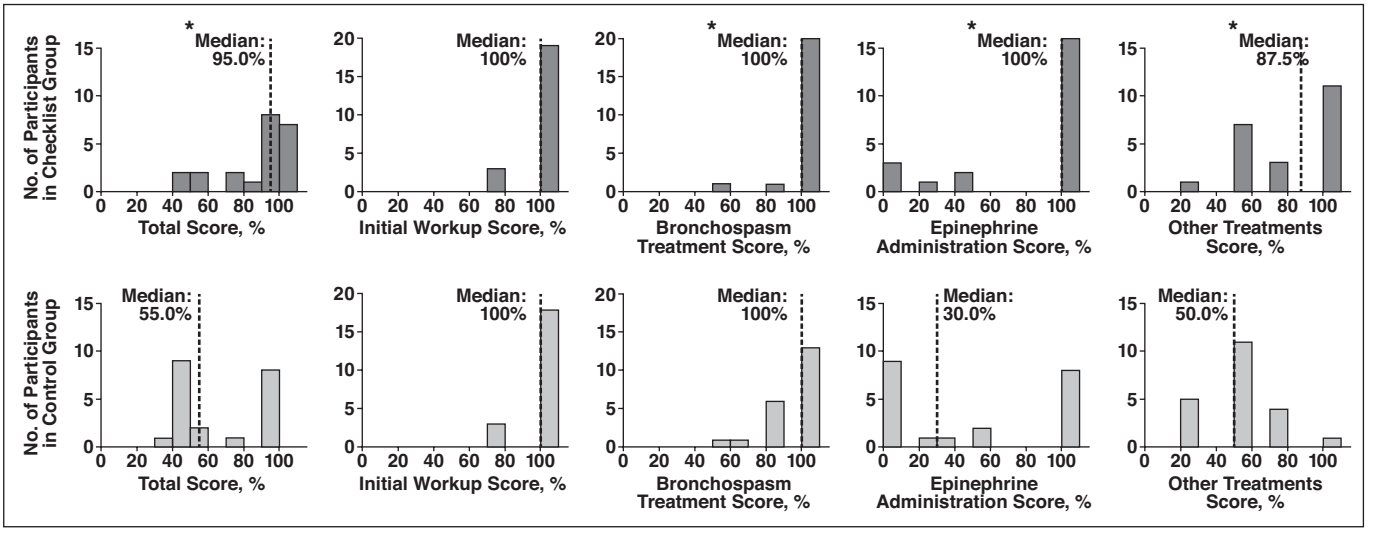


Fig. 2—Histograms illustrating distribution of total contrast reaction management score and score of each component (initial workup, first-line treatment of bronchospasm, epinephrine treatment, and other treatments) in checklist group ($n = 22$) and control group ($n = 21$). Dotted line indicates median score, and asterisk indicates significant difference in scores between two groups determined by Wilcoxon rank-sum test. Checklist group had significantly higher total contrast reaction management scores than control group ($p = 0.001$). Similarly, checklist group scored significantly higher in three of four components of contrast reaction management score ($p < 0.04$).

Statistical significance was defined by a two-sided $p < 0.05$. All statistical calculations were conducted using statistical computing and graphics software (R, version 3.1.1. R Foundation).

Results

Forty-three participants completed the study (22 in checklist group and 21 in the control group). At baseline, no significant differences in reported experience were noted between the groups (Table S1, which can be viewed in the *AJR* electronic supplement to this article, available at www.ajronline.org). Both the checklist group and the control group had similar scores on MCQ tests before the simulation (mean, 77.3% vs 80.5%, respectively; $p = 0.35$) and after the simulation (mean, 86.8% vs 84.8%, respectively; $p = 0.62$). As shown in Table 1, the checklist group had significant improvement in the MCQ test score after the simulation (mean, 77.3% vs 86.8%; $p = 0.006$). The improvement noted in the control group after the simulation was not statistically significant (mean, 80.5% vs 84.8%; $p = 0.54$) and tended to be smaller than that in the checklist group ($p = 0.068$). Both groups showed significant improvement in self-reported comfort levels with managing reactions, identifying reactions, administering medication, and administering the proper dose after the simulation, with no significant differences noted between the groups (Tables 1 and 2).

On the basis of the videos, all but one resident in the checklist group referred to the safety checklist at least once during the simulation. Objective and subjective scores for the checklist group and the control group are summarized in Table 2. Figure 2 shows the distributions of the objective scores. In the simulation, the checklist group performed significantly better than the control group in terms of contrast reaction management overall, on the basis of the objective assessment (mean, 85.1% vs 64.8%, respectively; $p = 0.001$). In particular, the checklist group performed significantly better than the control group in three of the four components of the total objective score: first-line treatment of bronchospasm (mean, 97.0% vs 91.3%; $p = 0.035$), other treatments (mean, 77.3% vs 51.2%; $p = 0.001$), and epinephrine actions (mean, 77.3% vs 45.2%; $p = 0.021$). The scores for the initial workup were high in both groups and were not significantly different (mean, 96.6% for the checklist group vs 96.4% for the control group; $p = 0.97$). More residents in the checklist group scored 100% on their epinephrine actions (16 residents [73%]), compared with those in the con-

TABLE 2: Objective and Subjective Scores for Checklist and Control Groups

Variable	Randomized Group		p[a]
	Checklist ($n = 22$)	Control ($n = 21$)	
Objective score (%)			
Contrast reaction management[b]	85.1 ± 20.3	64.8 ± 24.9	0.001[c]
Initial workup	96.6 ± 8.8	96.4 ± 9.0	0.97
First-line treatment of bronchospasm	97.0 ± 11.1	91.3 ± 13.6	0.035[c]
Epinephrine administration	77.3 ± 39.2	45.2 ± 46.5	0.021[c]
Other treatments	77.3 ± 25.5	51.2 ± 20.1	0.001[c]
CUS or 2-challenge rule	47.7 ± 16.5	38.9 ± 22.6	0.14
Subjective score (%)			
The resident assessed the patient well[d]	4.5 ± 1.0	3.9 ± 1.2	0.12
The resident identified the type of reaction well[d]	4.6 ± 1.1	4.0 ± 1.4	0.11
The resident administered medications well[d]	4.0 ± 1.3	3.0 ± 1.6	0.056
The resident treated the reaction well[d]	3.8 ± 1.5	2.9 ± 1.6	0.14
The resident had overall good performance[d]	3.9 ± 1.2	3.0 ± 1.5	0.15
Performed a CUS	4.2 ± 1.1	3.4 ± 1.4	0.027[c]
Performed two-challenge rule	4.5 ± 1.0	3.6 ± 1.7	0.11
Written test (%)			
Before simulation	77.3 ± 13.9	80.5 ± 19.9	0.35
After simulation	86.8 ± 11.3	84.8 ± 12.1	0.62
Questionnaire before simulation (%)			
Comfortable managing reactions	2.7 ± 0.9	3.0 ± 1.1	0.39
Comfortable identifying reactions	3.6 ± 0.7	3.6 ± 0.9	0.98
Comfortable administering the medication	2.9 ± 0.8	3.0 ± 1.0	0.97
Comfortable administering the proper dose	2.7 ± 1.0	2.7 ± 1.1	0.98
Questionnaire after simulation (%)			
Comfortable managing reactions	3.4 ± 0.8	3.8 ± 0.8	0.11
Comfortable identifying reactions	4.2 ± 0.7	4.3 ± 0.6	0.81
Comfortable administering the medication	3.7 ± 0.8	3.7 ± 1.0	> 0.99
Comfortable administering the proper dose	3.6 ± 0.7	3.7 ± 1.0	0.82

Note—Except where indicated otherwise, data are mean score (± SD). CUS = TeamSTEPPS approach in which potential safety issues are discussed by saying keywords such as "I am concerned," "I am uncomfortable," or "This is a safety issue" (with the three initial letters in the words "concerned," "uncomfortable," and "safety" forming the acronym CUS).

[a]Wilcoxon rank-sum test.

[b]Includes the four contrast reaction management areas (initial workup, first-line treatment, other treatments, and epinephrine administration) and not the conflict resolution area (CUS or two-challenge rule).

[c]Statistically significant.

[d]The data for five participants without usable videos were excluded from this subjective score category because scores could not be ascertained from the grader's notes.

TABLE 3: Number of Major Mistakes Made by Checklist and Control Groups

Critical Treatment Error Resulting in Morbidity	Checklist Group ($n = 22$)	Control Group ($n = 21$)
Respiratory and cardiopulmonary arrest	1/22 (4.5)	4/21 (19.0)
Administration of wrong medication (e.g., atropine)	2/22 (9.1)	5/21 (23.8)
Epinephrine overdose	3/22 (13.6)	7/21 (33.3)
Failure to flush IV line	0/6 (0.0)	4 /13 (30.8)

Note—Data are number of residents with error/total number of residents assessed (%).

trol group (eight residents [38%]) ($p = 0.03$), whereas the control group had a significantly higher number of residents with a 0% score on their epinephrine actions (nine residents [43%]), compared with the checklist group (three residents [14%]) ($p = 0.04$). On average, subjective scores of contrast reaction management performance were numerically higher in the checklist group than in the control group, although they did not reach statistical significance ($p = 0.056$–0.15) (Table 2).

The presimulation MCQ test scores were not significantly correlated with the total objective contrast reaction management score ($\rho = -0.02$; $p = 0.90$). The MCQ test score was significantly correlated with PGY ($\rho = 0.67$; $p < 0.001$), with mean scores of 65.8%, 74.2%, 85.6%, and 94.0% noted for residents in PGY2, PGY3, PGY4, and PGY5, respectively, whereas the total object contrast reaction management score was not significantly correlated with PGY ($\rho = 0.07$; $p = 0.67$).

Critical treatment errors resulting in morbidity were higher in each category for the control group compared with the checklist group (Table 3). This resulted in higher occurrences of respiratory and cardiopulmonary arrest (four vs one occurrence) caused by incorrect use of atropine to treat anaphylaxis when challenged by the confederate (five vs two occurrences); overdosing epinephrine, which resulted in chest pain (seven vs three occurrences); and forgetting to flush the IV line when administering IV epinephrine, resulting in the manikin having anaphylactic shock (four vs zero occurrences). Overall, only 24 residents administered the correct dose of epinephrine in a single try, 16 of whom were in the checklist group.

Objective conflict resolution scores in the checklist and control groups were not significantly different (mean, 47.7% vs 38.9%; $p = 0.14$), although the checklist group had numerically higher scores on average. In terms of subjective scores for conflict resolution, the checklist group had significantly higher scores for CUS performance than the control group (mean, 4.2 vs 3.4; $p = 0.027$) and numerically higher scores on two-challenge rule performance (mean, 4.5 vs 3.6; $p = 0.11$).

Discussion

Many publications have shown that radiologists, radiology nurses, hospital code teams, and other physicians commonly mismanage contrast reactions, particularly with regard to the proper dosing and administration of epinephrine, which may in part relate to inconsistent and infrequent hands-on experience managing moderate and severe reactions [4–6, 10, 27]. Elsewhere in health care, checklists are increasingly being used as tools to improve care processes and patient safety outcomes [15, 28–36]. Our study shows that using a safety checklist significantly improves contrast reaction management, as shown by resident performance in a simulated contrast reaction scenario resulting in fewer preventable human errors, which could potentially decrease real-life mortality and morbidity. It also shows that safety checklists may have the potential to increase the likelihood of challenging an unsafe and erroneous recommendation by a superior. To our knowledge, this is the first safety checklist based on the American College of Radiology Manual on Contrast Media that was specifically developed for contrast reaction management, and our results suggest it should be included in all contrast reaction management kits [25].

Of importance, we also found that using a safety checklist is not 100% effective and is ineffective if it is not used or is misused. In aviation, which relies heavily on safety checklists, a study showed that checklist misuse was a contributing factor in 228 accidents occurring since 1991 [37]. Similarly, in our study, all mistakes made in the checklist group could have been avoided if the resident had referred to the checklist. As such, it must be emphasized that a checklist works only when used correctly and that operators require proper training before widespread implementation of a checklist. Institutions should establish a checklist as an integral part of contrast reaction management and should ensure that operators are familiar with its layout and purpose so that it can be used effectively during a real contrast reaction. Operators should be trained to use a checklist at critical decision points (e.g., when identifying the type of reaction and when choosing and injecting a medication that may potentially cause harm in the case of overdose or underdose). Taking a shortcut while using a checklist or relying on memory are other pitfalls that may cause a checklist to fail. Without a checklist, the radiologist must rely on a conscious cognitive memory process to recollect the sequence of steps and correct dosage, which can become increasingly difficult in a stressful and chaotic situation.

Virtually all adverse effects associated with epinephrine administration result from IV administration because it requires an extra step (flushing the IV line) and can result in severe complications when administered incorrectly, including both underdosing and overdosing [38]. We also noted critical misadministration of IV epinephrine in both groups, although we noted it to a lesser extent in the checklist group. Specifically, residents tended to underdose IV epinephrine by failing to account for the dead space in the IV cannula and line [39]. All four residents who did not flush the IV were in the control group.

We believe that intramuscular (IM) epinephrine is safer, less prone to error, and easier to administer compared with IV epinephrine, and, as such, IM administration was the only route specified in our checklist. Not surprisingly, residents in the checklist group were more likely to give IM epinephrine, which may have helped result in fewer complications and higher scores in this group. Knowing or being able to check the correct dose and correct administration of IM epinephrine is important because technical failures in many of the prefilled autoinjectors (e.g., EpiPen by Pfizer) may still occur for a significant number of physicians, during either autoinjection or unsuccessful administration of the epinephrine [40]. A single-institution survey found that respondents were more likely to recall the proper dose for IM epinephrine than for IV epinephrine [6]. In addition, it has been shown that treatment with IM epinephrine is faster than treatment with IV epinephrine [41], although the same study did not find that errors in administration were reduced when IM epinephrine was used compared with IV epinephrine.

In a 2013 survey on workplace intimidation conducted by the Institute for Safe Medication Practices, 44% of respondents reported they had questions about the safety of an order in the past year but decided to assume that the order was correct rather than interact with a prescriber they perceived as intimidating [42, 43]. Improving communication skills among radiologists is critical for patient safety, yet it is rarely formally taught during training. Since 2010, we have incorporated TeamSTEPPS into our institution's onboarding for residents. Our data suggest that communication skills should be given higher priority in radiology training. Despite both groups' high reported confidence and comfort in managing the contrast reaction, six residents (two in the checklist group and four in the control group) still administered the wrong medication and failed to express concern in the face of an incorrect order from a superior, sometimes in spite of obvious signs of discomfort in the body language of the residents. This highlights the persistent role of hierarchy in medicine, including the potential for intimidation and its effect on safety. Our study reveals that both groups failed to master the communication skills of correctly expressing concern and

resolving conflicts, receiving less than 50% of the total points possible (Table 2). More training and experience could help improve communication skills in day-to-day radiology practice.

The sample size in the present study was limited because of the size of our residency program. We hope that future efforts are directed to evaluating the efficacy of this checklist on a larger scale with a multiinstitutional study design. Our graders were not blinded to the group assignments because the checklist could be seen in the participant's hands in the videos. However, the graded scores were based more objectively on whether they performed the action or not, with only the global scores having more subjectivity to the grading. In future studies, this issue could be alleviated by giving the control group a similar-appearing sheet of paper without the checklist printed on it. We attempted to reduce the unfamiliarity bias for the checklist group in our study by having them review the checklist for 2 minutes before the scenario. However, this may have introduced bias because the control group did not go through the same process, which may have given the checklist group an advantage over the control group. Anecdotally, several of the participants in the checklist group gave only cursory glances at the checklist and did not use the full 2 minutes to review the checklist. Also, our institutional policies dictate that epinephrine should be administered IM for anaphylaxis, and therefore only information regarding IM epinephrine injection was included in the checklist. The checklist group may have potentially had better results if the checklist had been introduced to them at the time of contrast reaction management training 3–6 months before the study and if it had included the IV epinephrine information.

Conclusion

In summary, a standardized contrast reaction management checklist reduced the number of critical treatment errors during a severe contrast reaction management simulation, including errors in the proper administration of epinephrine and treatment of bronchospasm. Such a checklist could be used by radiologists, technologists, and nurses to improve patient safety for both contrast reaction management and teamwork skills.

Acknowledgment

We thank the WWAMI Institute for Simulation in Healthcare (the University of Washington's premiere simulation training facility for health care education serving Washington, Wyoming, Alaska, Montana, and Idaho) and its personnel for their help with this study.

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APPENDIX 1: Team Scenario Final Test Script

Confederate #1: Technologist **(Tech)**
Confederate #2: Body attending **(ATTENDING)**
Patient manikin (in gown and has IV line)

Orientation

- Manikin intro; includes how to administer atropine
- Mention that they are at UWMC (UWMC-specific codes and phone #s)

Important Reminders

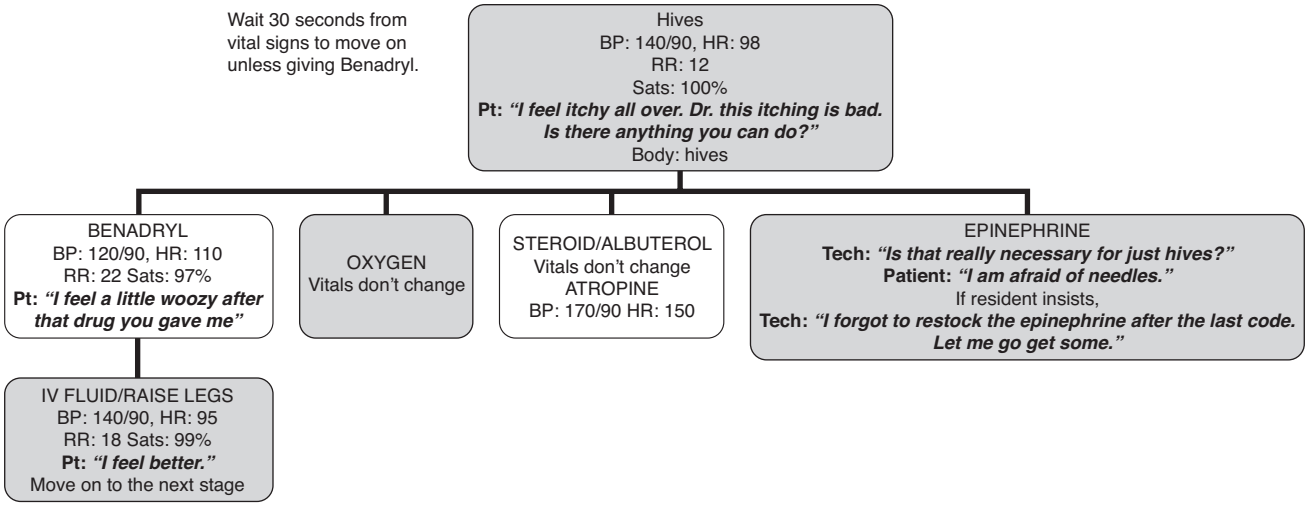
: DO NOT PROMPT unless they don't verbalize the medication/dose/route. Clarify something team already talked about. (Ex. Don't prompt IV epi flush).
: Participants may say one thing but do another!
: Make sure the team and tackle box are within view of the video camera (floors will be marked with tape).

Scenario

Tech: "Doctor I need some help with a patient." *(Tech brings the resident into the simulation laboratory.)* "This is Chris Jones, he's a 35-year-old man who is here for a CT scan to evaluate for a possible mass in his abdomen who started to complain about itching after receiving the IV contrast."
Patient (a tech not present in the room operating and speaking for the manikin): "I am feeling itchy all over, especially my chest. Is this normal?"
Tech: *(Wheel table with tackle box by the head of the bed on the left side and, make sure it's within marked lines on the floor!)*

>> If needed, clarify whether a medication was given.

>> If the resident has not listened to the lungs after the patient complains of shortness of breath, "Do you think you should listen to the lungs?" *(Hold out stethoscope over patient's chest)*



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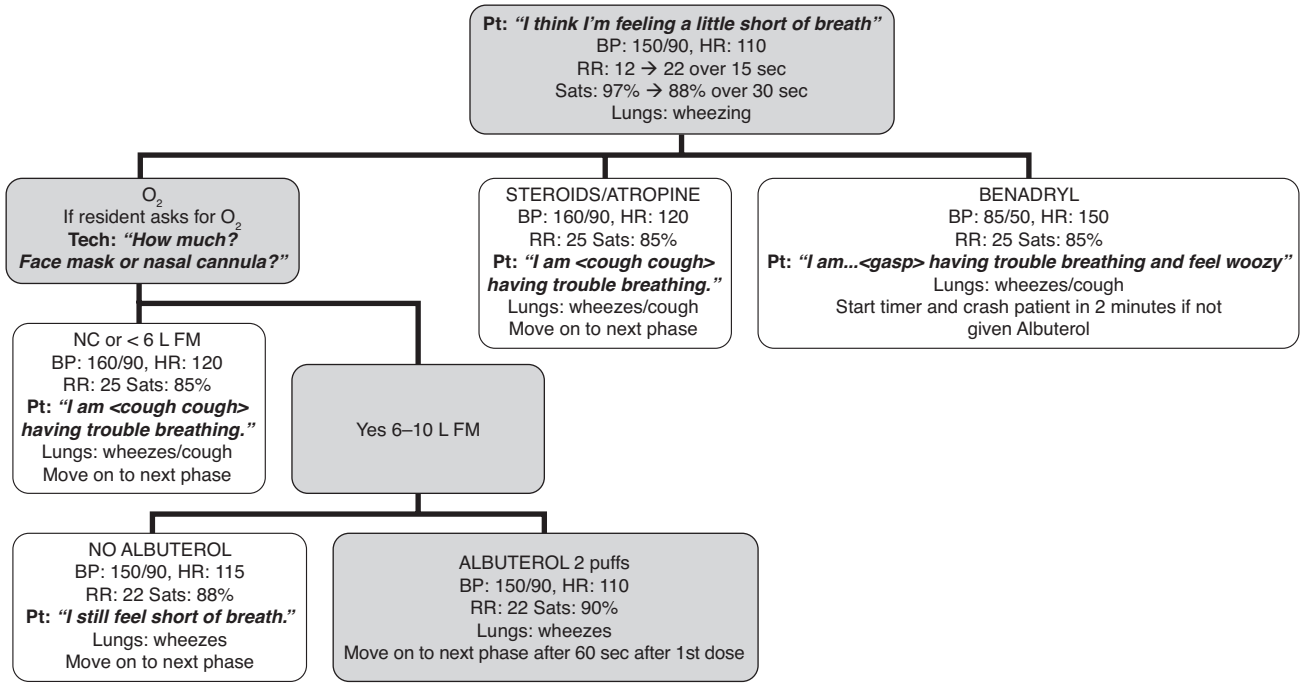
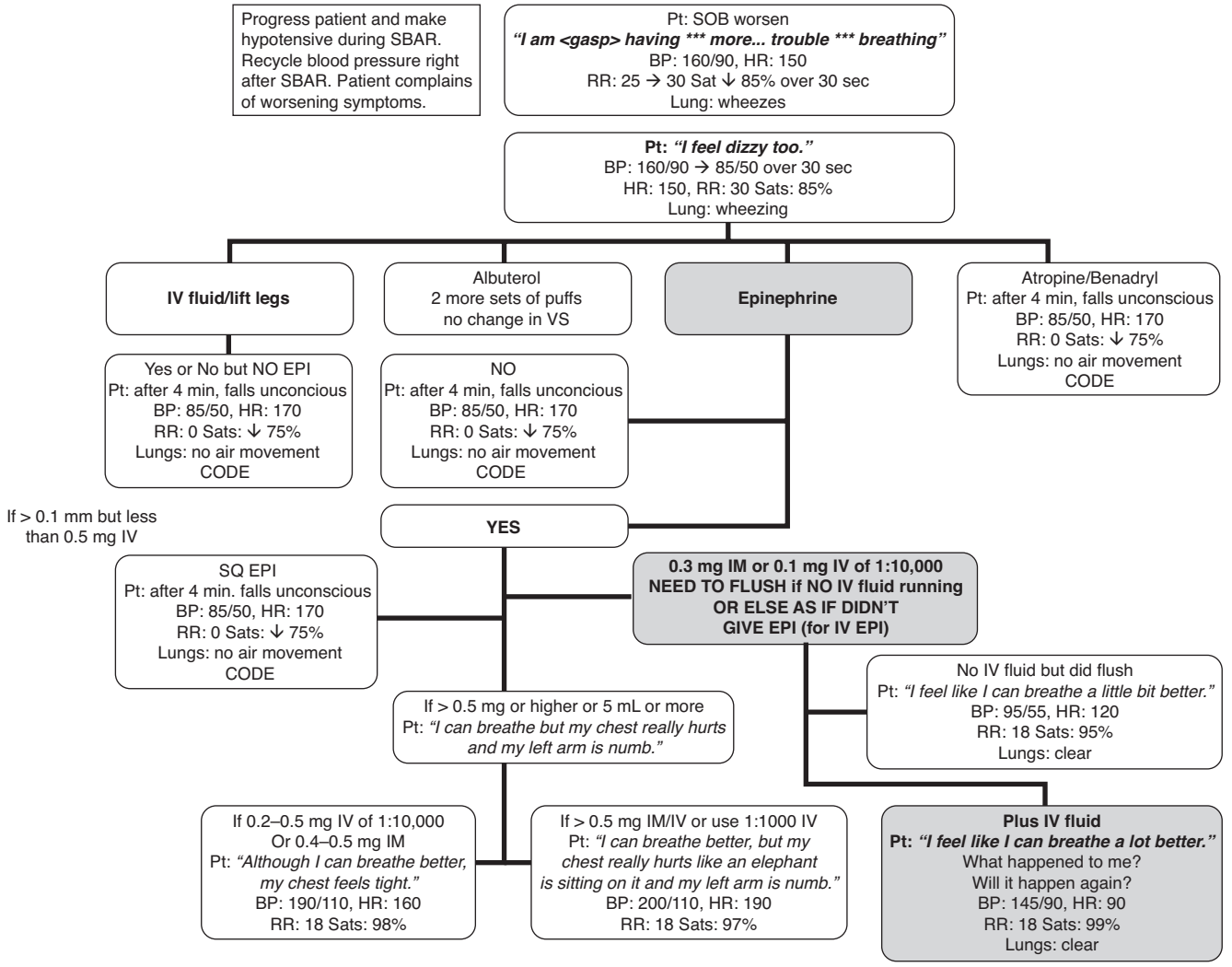


ATTENDING (Confederate #2) *walks in after the first dose of albuterol*. "Hi, I'm the new body attending Dr. Smith. What is going on here?"



(Appendix 1 continues on next page)

When patient is hypotensive,
ATTENDING: "The patient's BP is low. I think we should give 1 mg of atropine IV."

Force a Two-Challenge Rule
ATTENDING: "No, we should give 1 mg of atropine IV."
> If resident proceeds with CUS and counters attending again, say, "It's been a while since I've reviewed this information, so why don't you go ahead."

After completion of treatment, and Code is NOT called:
ATTENDING: "What is your/our plan for the patient?"

END OF SCENARIO

APPENDIX 2: Contrast Reaction Management Grading for the Final Scenario

There are two parts to the grading: recording whether specific actions were taken or not (objective) as well as more overall subjective assessment. For the objective portion, 4 skill areas will be graded:

- Initial workup and evaluation
- Other treatments
- First-line treatment
- Epinephrine

For each sub-item of each skill, all that is needed is a check mark to indicate that it happened. If an action did not occur, you may leave that cell blank.

Please familiarize yourself with all the items being graded before watching the video. Some items will tend to happen in the order on the grading sheet but some may happen out of order or may need to be assessed at the end of the video.

When grading the objective and subjective portions, focus specifically on the contrast reaction management skills identified in the items below. Communication and team skills are graded separately.

You are encouraged to pause and rewind the video while grading to help ensure actions are not missed. Some actions may overlap or happen quickly so it is difficult to grade completely with only a single continuous pass through the video.

Lastly, points are assigned for the actions completed and not for actions that were only vocalized or requested but not actually performed. You may rely on statements by the participants to determine if the correct dosages were administered. Please comment if you notice a discrepancy between the treatment given and response of the manikin and it will be flagged for re-review.

Resident name: _____ ☐ **Check if HAS checklist**
☐ **Check if USED checklist**

1. Initial Workup and Evaluation (10%)

Check the box for each item performed.

Action Item	Performed
Performed physical examination	
Checked vital signs	
Checked pulse ox	
Auscultated lungs (only count if after shortness of breath and not prompted)	

2. Other Treatments (10%)

Check the box for each item performed (or not performed) before epinephrine is administered.

Action Item	Performed
Gave IV fluids (only count if before epi)	
Raised legs (only count if after noting hypotension and before epi)	
Gave atropine to the patient* (Improper action)	
Called a CODE	

(Appendix 2 continues on next page)

3. First-Line Treatment (30%)

After patient complains of shortness of breath, resident should first try administering oxygen and then albuterol before epinephrine. Participant will only get points for the following actions if performed before epinephrine.

Action Item	Performed Before Epi
Gave oxygen	
Gave oxygen before albuterol	
Used face mask instead of nasal cannula	
Gave correct dose of oxygen (6–10 L by FM)	
Gave albuterol	
Gave correct dose of albuterol (2 puffs)	

4. Epinephrine Administration (50%)

If resident administers epinephrine multiple times (IM or IV), you may grade their best one. However, the last item (delivered epi in proper dose in a single try) can only be checked if their first attempt was entirely correct!

Action Item	Performed
Gave SQ epi to hypotensive patient*	
Gave IV epi	
Gave IM epi	
Gave ≥ 1 mg IV or IM epi*	
Gave 1:1000 IV epi*	
Gave proper dose and concentration (Either in 1 part or multiple)	
Flushed or had fluids running (IV epi only)	
Patient went into respiratory arrest/became unresponsive*	
Patient went into cardiopulmonary arrest/no heartbeat*	
Delivered epi in proper dose in a single try (Requires flush or fluids for IV epi and no SQ epi)	

*Note: this is an improper action or unfavorable outcome and resident will lose 1 point out of 10 total points.

- Gain 1 point for not giving SQ epi to hypotensive patient
- Gain 1 point for giving IV or IM epi
- If IV epi
  - Gain 1 point for giving proper dose and concentration
  - Gain 1 point for flushing/fluids running
- If IV epi
  - Gain 2 points for giving proper dose and concentration
- Gain 1 point if patient does not go into respiratory arrest/become unresponsive
- If epi was given in proper dose and concentration (w/ flushing for IV epi) in a single try, gain additional 5 points
- Lose ALL points if patient given ≥ 1 mg epi or 1:1000 epi IV or if patient went into cardiopulmonary arrest/no heartbeat

(Appendix 2 continues on next page)

Global Subjective Scores

The following statements refer to the actions needed to identify and manage the contrast reaction. Please do not include opinions about teamwork in the assessment when possible to separate from actions related to contrast reaction management.

Check 1 option for each statement.

Statement	1 Strongly Disagree	2 Disagree	3 Neutral	4 Agree	5 Strongly Agree
The resident assessed the patient well					
The resident identified the type of reaction well					
The resident administered medications well					
The resident treated the reaction well					
The resident had overall good performance					
Performed a CUS (concerned, uncomfortable, safety)					
Performed 2-challenge rule					

CUS/2-Challenge Rule (check if done)

Resident questioned atropine 1st time	
Resident questioned atropine 2nd time (2-challenge rule)	
Resident used the word "concerned"	
Resident used the word "uncomfortable"	
Resident used the word "safety"	
Resident did NOT give atropine	

FOR YOUR INFORMATION

The data supplement accompanying this web exclusive article can be viewed by clicking "Supplemental" at the top of the article.