

Enhancing Pediatric Safety: Using Simulation to Assess Radiology Resident Preparedness for Anaphylaxis from Intravenous Contrast Media¹

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Purpose:

To prospectively develop and test a simulation model for assessing radiology resident preparedness for pediatric life-threatening events in the radiology environment.

Materials and Methods:

This study was institutional review board approved. Nineteen radiology residents (10 men, nine women; mean age, 28.5 years) participated in two simulated contrast material reaction scenarios: one with and one without resuscitation aids available. Each resident examined and managed two mannequins—simulating a 1–2-year-old patient and an 8–9-year-old patient—for type, sequence, dose, and administration route for any intervention, including administering medication, calling a code team, and providing oxygen. The time to order each intervention was documented. Resident responses (time to order intervention, appropriateness of intervention, and intervention route) were evaluated. The paired *t* test was used to compare the time to intervention between the resuscitation-aid-available and resuscitation-aid-not-available scenarios and between the scenario performed first and the scenario performed second. The McNemar test was performed to compare the percentage of appropriate interventions between the two resuscitation aid scenarios.

Results:

The average time to call the code team was shorter when no resuscitation aids were available than when resuscitation aids were available (98 vs 149 seconds, $P = .08$). The average times to request oxygen and epinephrine were shorter when resuscitation aids were available (40 vs 89 seconds to request oxygen, $P = .016$; 121 vs 163 seconds to request epinephrine, $P = .21$). Appropriate medication dosing was not significantly different between the two scenarios. In only five of the 38 simulated scenarios was calling the code team the first intervention. The correct sequence of interventions (calling code team, providing oxygen, and then providing epinephrine) was performed by only one resident in one scenario. Only five residents recognized that they were encountering a contrast material reaction.

Conclusion:

Simulation training for radiology residents is valuable and suggests that resident preparedness for pediatric anaphylaxis from intravenous contrast media is insufficient. Clear step-by-step resuscitation aids are needed in the radiology environment.

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One of the adverse events of medical care recognized by radiologists is the reaction to intravenous contrast media. Moderate to severe reactions to intravenous contrast material are very rare, with an incidence of 0.05%–0.08% in the general population (1,2). Life-threatening reactions in children occur even more uncommonly (3). A review of 10 independent studies on the safety of nonionic contrast material in pediatric patients revealed that in 819 patients who received intravenous contrast material, only one severe reaction, dyspnea, was noted (4). The rarity of these events at any age, however, has led to a relative inexperience among radiologists in addressing these events. For example, a 2003 survey of radiologists and trainees revealed that only 43% of those surveyed knew the appropriate dose of epinephrine to administer in the case of an adult anaphylactic reaction, with the majority of incorrect epinephrine dose decisions being overdoses (5). In the clinical arena, it has been shown that, owing to the wide spectrum of body sizes in the pediatric population, the difficulty in appropriately treating emergency conditions in children is greater (6). Therefore, the appropriate interventions for emergent or life-threatening contrast material reactions in children in the radiology setting are also

more likely to be unfamiliar to radiologists.

In the emergency department, the use of resuscitation aids such as Broselow-Luten tape (Vital Signs, Totowa, NJ) for pediatric emergencies has been shown to reduce instances of inappropriate medication dosing (6,7). The length of a pediatric patient is measured from the head to the toe with Broselow-Luten tape, and on the basis of this length, the patient is assigned a color-coded zone. For each zone, emergency care physicians are provided with predetermined, precalculated medication doses, dose delivery volumes, and equipment sizes based on the height-weight correlation. For example, a patient 75–85 cm in length would be assigned to the purple zone on the Broselow-Luten tape, which correlates with a weight range of 10–11 kg (22.0–24.2 lb) (Fig 1). Broselow-Luten tape is used to estimate lean body weight on the basis of length, and using it may lead to underestimation of weight in the setting of obesity (7). To our knowledge, no such resuscitation aids had been tested for the clinical management of children in the radiology environment during an emergent or life-threatening condition such as an anaphylactic reaction to intravenous contrast media. Thus, the purpose of our study was to prospectively develop and test a simulation model for assessing radiology resident preparedness for a pediatric life-threatening event in the radiology environment.

mation were created. These sheets were modified from the Broselow-Luten tape by using the same eight length- or weight-appropriate color zones. The appropriate range of vital signs; the medications, medication doses, and medication administration routes; the required amounts of intravenous fluid required for management; and the size of equipment necessary for respiratory support in the management of anaphylactic reactions were listed on these sheets (Fig 2). The listed drug concentrations and doses were reviewed by a pediatric pharmacologist for accuracy.

First- and 2nd-year radiology residents were asked to participate in this investigation, which was performed during a 1-day session. There were no consequences to refusing to participate, and all residents who were asked agreed to participate. Residents were asked not to discuss the scenarios after completion; the intent was to minimize subsequent residents' preparation for the scenarios. The demographic data for each resident were recorded and included year of training, type of internship (ie, medicine, surgery, transitional, etc), and any life support certification (ie, basic, advanced cardiac, or pediatric advanced life support).

Resident Assignments and Contrast Material Reaction Scenarios

Next, each resident took part in two intravenous contrast material anaphylactic scenarios. In one scenario, the

Advances in Knowledge

- First- and 2-year radiology resident preparedness for managing pediatric anaphylaxis from intravenous contrast media is insufficient.
- The availability of resuscitation tools does not guarantee substantial improvement in a resident's response to a contrast material reaction emergency.
- There is need for a clear step-by-step resuscitation tool that includes reminders to call for assistance and provides a limited number of specific interventions to stabilize a patient until assistance arrives.

Materials and Methods

Participants

This investigation was approved by the institutional review board of Duke University Medical Center, and signed informed consent was obtained from each participating resident. Before the trial portion of this investigation, information sheets with radiology-specific infor-

Implication for Patient Care

- The availability of radiology-specific resuscitation tools can facilitate improved patient safety.

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See also the editorial by Becker in this issue.

resident was given 5 minutes of training in the use of the Broselow-Luten color-coded system with the accompanying radiology-specific medication sheets and was then allowed to use these aids during the contrast material reaction simulation. This was designated the scenario with resuscitation aids available. In the other scenario, the resident was not given access to the color-coded system but rather had to rely on prior training and experience, as well as any aids for emergency situations that he or she might carry during the course of a normal work day. This was designated the scenario without resuscitation aids. At evaluation of the effects of resuscitation aids, one potential confounding factor is the learning effect—that is, enhanced performance in the second scenario due to participation in and experience gained from the first scenario. To minimize learning effects, the residents were randomly assigned to first participate in the contrast material scenario with the resuscitation aids available and then in the scenario without the aids available or to first participate in the scenario without the aids available and then in the scenario with the aids.

Two pediatric-size mannequins weighing 10 kg (simulating a 1–2-year-old child) or 25 kg (simulating an 8–9-year-old child) were used to represent children during these scenarios. The residents were also randomly grouped with respect to the size of mannequin used for the first scenario, with the other mannequin used for the second scenario. The purpose of using mannequins of two sizes was to minimize recollections of the medication doses administered between the two scenarios.

The same intravenous contrast material reaction scenario was presented to the residents by a single facilitator (S.M.H.) trained in the emergency resuscitation of pediatric patients (8,9). This facilitator also functioned as the first-responder radiology nurse on the scene to help with initial central venous catheter access and subsequent clinical management of the patient for the procedure. The contrast material reaction scenario was that of an inpatient child with a chronic infection and a central

venous catheter for antibiotic therapy: The patient is given a 3–5-mL dose of nonionic intravenous contrast material to check the function of the catheter, which, owing to difficulty in flushing, is clinically suspected of having a tip thrombosis. The catheter function test result is normal, revealing no thrombosis. One minute after the contrast material administration, the patient becomes diaphoretic and begins to wheeze. When the scenario involves the larger mannequin, the patient also reports having chest tightness. Vital signs are reported as a routine part of each scenario: The heart rate is 190–200 beats per minute, the blood pressure is 70/20 mm Hg, and the oxygen saturation at pulse oximetry is 89%–90%.

During a subsequent timed period limited to exactly 5 minutes, the facilitator supplied the resident with continuous standardized clinical data and answered any questions regarding the status of the simulated patient. Five minutes was chosen to represent the approximate time it would take for the pediatric code team to arrive and take over the care of the child. Additional information was made available by the facilitator through a select list of responses (eg, additional or changing vital signs, skin color, and responsiveness). These responses varied according to the type of response or question from each resident, so there was some variability in the prompts and responses for each scenario.

Each resident was asked to assess the patient during the scenario and make treatment decisions, including determining the specific type, sequence, dose, and route of any medications ordered. A pediatric radiology technologist (A.A.) was present in the room with the resident during the contrast material reaction to follow any treatment orders without providing guidance. The scenarios took place in a fluoroscopy suite that is normally used for pediatric examinations and that houses all of the emergency equipment normally available in a radiology suite—for example, a pediatric code cart, a pulse oximeter, and a full range of pediatric support apparatus such as nasal cannulas and non-rebreather bags and masks in a complete range of sizes for pediatric care. Digital video cameras were used to videotape all of the scenarios from two orthogonal positions to maximize audio recording. The facilitator also made notes during the scenarios to corroborate the videotaped information. All scenarios were completed during one 7-hour period.

Digital Video Disc Review and Resident Evaluation

All scenarios were transferred to digital video discs, which were then independently reviewed by two observers (A.M.G., S.M.H.). Each scenario was reviewed in the sequence in which it happened. The data were collected by us-

Figure 1

RED		PURPLE		YELLOW	
RAPID SEQUENCE INTUBATION		RESUSCITATION		RAPID SEQUENCE INTUBATION	
PREMEDICATIONS 0.005 mg/kg (0.05 mL) Atropine 0.01 mg (0.01 mL) Pan/Venocurium 0.01 mg (0.01 mL) (Defasciculating Agent) 0.17 mg Lidocaine 0.5 mL Fentanyl		PREMEDICATIONS Epinephrine 1st Dose (1:10,000) 0.1 mg/1 mL Epinephrine High Dose/TT (1:1,000) 1 mg/1 mL Atropine 0.21 mg Sodium Bicarbonate 10 mEq Lidocaine 10 mg Fentanyl 10 mg		PREMEDICATIONS Atropine 0.21 mg Pan/Venocurium (Defasciculating Agent) N/A Lidocaine 10 mg Fentanyl 32 mcg	
INDUCTION AGENTS 17 Joules Etomidate 17 Joules Ketamine 17 Joules Midazolam 20 Joules Propofol		INDUCTION AGENTS First dose 20 Joules Second dose (may repeat) 40 Joules Cardioresuscitator 10 Joules Adrenaline 1 mg 2nd Dose if Needed 2.5 mg Amiodarone 50 mg Calcium Chloride 210 mg Magnesium Sulfate 525 mg		INDUCTION AGENTS Etomidate 3.2 mg Ketamine 21 mg Midazolam 3.2 mg Propofol 32 mg	
PARALYTIC AGENTS Succinylcholine (give atropine prior) 17 mg 0.85 mg Pancuronium 1.7 mg Vecuronium 170 mg Rocuronium		PARALYTIC AGENTS Succinylcholine (give atropine prior) 20 mg Pancuronium 2.1 mg Vecuronium 2.1 mg Rocuronium 10 mg		PARALYTIC AGENTS Succinylcholine (give atropine prior) 20 mg Pancuronium 2.1 mg Vecuronium 2.1 mg Rocuronium 10 mg	
MAINTENANCE 405 mg Pancuronium/Venocurium Lorazepam 0.4 mg		MAINTENANCE Pancuronium/Venocurium 1 mg Lorazepam 0.5 mg		MAINTENANCE Pancuronium/Venocurium 1 mg Lorazepam 0.5 mg	
KG		10 KG		11 KG	
9 KG		10 KG		12 KG	

Figure 1: Pediatric intravenous contrast material reaction scenario. Purple zone from Broselow-Luten pediatric emergency tape shows precalculated medications for emergency department resuscitation of patients weighing 10–11 kg.

ing stopwatches and included the timing, type, and sequence of interventions performed. If there was a difference in opinion regarding whether an intervention had been performed or the timing of the intervention, the video discs were reviewed again and a consensus was reached.

Resident responses were evaluated for the appropriateness of the sequence in which the interventions were pre-

formed. The amount of time required to perform each action was documented and evaluated. All interventions suggested by the resident, including medication and intravenous fluid administrations, were documented. Resident responses were also evaluated for the appropriate dose and administration route of any medication ordered, as well as for the appropriate size of any resus-

citation equipment used. Data were recorded on a standardized score sheet (Fig 3), and any disagreements were discussed to reach a consensus. Among the approximately 400 potential interventions, including providing medication and determining the dose and route of medication, there were seven discrepancies, and these were usually related to poor audio quality of the video disc. Discrepancies were resolved by using the written notes taken by the facilitator during the scenarios.

Figure 2

For Internal Use Only
3 PURPLE TREATMENT
CT SUITE

Zone Weight: 9.5-11.4 kg (20.9-25.1 lbs)
Zone Avg Wt: 10.5 kg (23.1 lbs)
Zone Length: 75.3-84.8 cm
Zone Age: 11.5 mo. – 22 mo.

Normal Vital Signs:

Respiratory Rate (breaths/min) 20-30
Pulse Rate (bpm) 120-140
Blood Pressure Systolic (mm Hg) 70-120

SEDATION

Medication	Brand	Route	Dose
Pentobarbital	Nembutal	IV	20mg (0.4ml of 50mg/ml) titrate to effect—not to exceed 60mg total
Choral Hydrate		PO	950mg (9.5ml of 500mg/5ml)
Fentanyl	Sublimaze	IV	10mcg (0.2ml of 100mcg/2ml)—not to exceed 40 mcg total
Midazolam	Versed	IV	0.5mg over 2 minutes titrate to effect (0.5ml of 2mg/2ml)

Reversal Agents

Medication	Brand	Route	Dose
Naloxone	Narcan	IV	1mg (2.5ml of 0.4mg/ml)
Flumazenil	Romazicon	IV	0.1mg (1ml of 0.5mg/5ml)

ALLERGIC REACTION

Diphenhydramine	PO	10mg (4ml of 12.5mg/5ml)
Diphenhydramine	IV	10mg (0.2ml of 50mg/ml)
Epinephrine (1:1000)	SC	0.1mg (0.1ml of 1mg/ml)
Albuterol Nebulized (PRN)		1.6mg (1.9ml of 2.5mg/3ml vial) + 3ml NS q15'prn
Methylprednisolone	IV	12mg (0.3ml of 40mg/ml)

FLUIDS

Bolus 105-210ml LR or NS IV Push
Maintenance D5W + 1/4NS + 20mEq KCL/liter @ 45ml/hr

STEROID PREPARATION (Corticosteroids)

Prednisolone (PO)	6mg (2ml of 15mg/5ml)	Q6hrs x 4 doses
Methylprednisolone(IV)	5.2mg (0.13ml of 40mg/1ml)	Q6hrs x 4 doses

Figure 2: Information sheet, modified from Broselow-Luten tape, with radiology-specific information for use in pediatric intravenous (IV) contrast material reaction emergencies. KCL = potassium chloride, LR = lactated Ringer solution, NS = normal saline, PO = by mouth, PRN and prn = as occasion requires, SC = subcutaneous.

Appropriate Responses

According to the American Heart Association's standards for advanced cardiac life support and pediatric advanced life support, on recognizing the need to respond to an emergency, a person should assess the victim, call for help or dial 911, and then safely position the patient for further action. This sequence of events is followed by the primary "ABC" resuscitation sequence, during which the care provider should assess the airway, assess and manage the breathing, and evaluate the blood circulation. In the described scenarios, the patient's vital signs were provided, so the primary "ABCs" were not assessed. Rather, this investigation was focused on the residents' actions on hearing the patient's condition. For our anaphylactic scenarios, in accordance with advanced cardiac life support and pediatric advanced life support standards, the interventions considered to be essential included calling a code team, providing the patient with oxygen through a non-rebreather mask, and giving the patient epinephrine with the appropriate dose and route of administration. The appropriate sequence of interventions was determined to be as follows: call a code team, provide oxygen, and then administer epinephrine.

Oxygen was considered to have been administered appropriately when high-flow (>5 L) oxygen was administered through a nonrebreather mask that was the appropriate size for the simulated patient. Epinephrine was considered to have been administered appropriately when it was given in the appropriate dose for patient size and via

the correct route. For example, for the 10-kg mannequin, which was assigned to the purple zone of the Broselow-Luten tape, an appropriate epinephrine dose would be 0.1 mg of epinephrine at a 1:10 000 ratio given intravenously. According to the American College of Radiology *Manual on Contrast Media*, epinephrine administered subcutaneously at a 1:1000 ratio is appropriate for minor contrast material reactions that progress, while intravenous epinephrine at a 1:10 000 ratio is required for severe reactions (10). Since the resident was provided with precalculated doses for epinephrine in both concentrations, the medication was considered to have been appropriately administered when either concentration was administered via the correct route and in the correct dose for the patient—for example, the correct dose of epinephrine at a 1:1000 ratio injected subcutaneously.

Statistical Analyses

A paired *t* test was performed to compare the average times to order an intervention when the resuscitation aids were available and when they were not available. A paired *t* test was also used to compare the average times to order an intervention between the scenario performed first—which could have been with or without the resuscitation aids—and the scenario performed second. The McNemar test was performed to compare the percentages of residents who administered the correct dose of medication appropriately when the resuscitation aids were available and when they were not available. All analyses were conducted by using SAS 8.0 (Statistical Analysis System, Cary, NC) software with only those residents who performed interventions in both scenarios. *P* < .05 was considered to indicate statistical significance.

Results

Nineteen radiology residents (10 men, nine women; mean age, 28.5 years) participated in this investigation. The most common type of internship was a transitional year internship (*n* = 8), followed by internal medicine (*n* = 6), prelimi-

Figure 3

Resident Data		
Participant Number (1-19)		
Code Scenario	___ 1 st	___ 2 nd
Aids Available:	___ Yes	___ No
Used Broselow Tape	___ Yes	___ No
Used Color Code Sheets	___ Yes	___ No
Resident Year	___ 1 st	___ 2 nd
Sex	___ Male	___ Female
Scoring		
Called Code	___ Yes – time _____	___ No
Oxygen:		
- Given	___ Yes – time _____	___ No
- Route	___ Nasal cannula	___ NRB
- Rate _____		
Epinephrine:		
- Given	___ Yes – time _____	___ No
- Concentration	___ 1:1000	___ 1:10,000
- Route	___ Subcutaneous	___ IV
Other Interventions:		
___ Fluids		
- Correct Rate	___ Yes	___ No
___ Albuterol		
___ Benadryl		
___ Other		

Figure 3: Scoring sheet for evaluating radiology resident's responses to pediatric contrast material reaction. IV = intravenous.

Table 1

Essential Interventions Used in Pediatric Intravenous Contrast Material Reaction Scenarios		
Intervention	Without-Aid Scenario	With-Aid Scenario
Call for code team	13 (34)	13 (34)
Provide oxygen	14 (37)	13 (34)
Provide epinephrine	15 (39)	14 (37)

Note.—Data are numbers of resuscitation aid scenarios (*n* = 38) in which the given interventions were performed, with percentages in parentheses.

nary internal medicine (*n* = 3), and surgery (*n* = 2) internships. The preliminary internal medicine internship offered major internal medicine exposure plus elective time, primarily to residents who were going on to residencies in specialties outside of internal medicine. All residents had current certification in basic and advanced life support; one resident had pediatric life support certification. Since each resident participated in

two intravenous contrast material reaction scenarios, the total number of scenarios was 38: 19 with and 19 without resuscitation aids available.

Essential Interventions

Calling the code team.—In 26 (68%) of the 38 (19 residents times two scenarios) scenarios, the resident called for the code team (Table 1), with an equal number calling for assistance, regard-

less of whether resuscitation aids were available (13 scenarios with and 13 without resuscitation aids). Conversely, in 12 scenarios, the resident never called for the code team, even when he or she was prompted by the question, "Is there anyone else you would like in the room?". Resident responses to this question usually included calling an attending radiologist or radiology fellow, which was considered an incorrect response. The amount of time between hearing the patient's condition in the simulated scenario and calling for a code team ranged from 9 seconds to 3 minutes 24 seconds for all residents who called for the code team. Twelve residents called for the code team during both scenarios. When only these residents' responses were analyzed, the average time to call the code team was shorter when no resuscitation aids were available (98 seconds) than when aids were available (149 seconds), but the difference was not significant ($P = .08$) (Table 2). Additional analyses were conducted to compare the times to call the code team between the first and

second scenarios, regardless of whether resuscitation aids were available. The average time to call the code team was shorter in the second scenario (95 seconds) than in the first scenario (150 seconds, $P = .052$) (Table 3).

Oxygen administration.—In 27 (71%) of the 38 scenarios, the resident administered oxygen to the simulated patient; no oxygen was offered in 11 scenarios (Table 1). Twelve residents administered oxygen in both scenarios. Of these residents, nine administered oxygen appropriately without resuscitation aids and nine administered it appropriately with resuscitation aids. The average time to administer oxygen was significantly shorter when the resuscitation aids were available (40 seconds) than when they were not available (89 seconds, $P = .016$) (Table 2). When asked how to provide oxygen to the simulated patient, resident responses ranged from 2 L by way of nasal cannula to 10 L through a 100% nonrebreather mask to intubation.

Epinephrine administration.—In 29 (76%) of the 38 scenarios—14 scenar-

ios with and 15 scenarios without resuscitation aids available—the resident requested that epinephrine be administered to the simulated patient (Table 1). Of the 15 residents who ordered epinephrine without available resuscitation aids, two used dose cards that were in their possession at the time of the reaction scenario. Thirteen residents ordered epinephrine during both scenarios. Three (23%) of these residents ordered epinephrine appropriately when resuscitation aids were not available compared with seven (54%) who ordered it appropriately when aids were available ($P = .45$). For those residents who administered epinephrine in both scenarios, the average time to order epinephrine was shorter when resuscitation aids were available than when the aids were not available (121 vs 163 seconds), but the difference was not significant ($P = .21$) (Table 2). Further analysis revealed that the average time to order epinephrine was significantly shorter in the second scenario than in the first scenario (103 vs 181 seconds, $P = .01$), regardless of whether resuscitation aids were available.

Sequence of essential interventions.—In 15 of the 38 scenarios, all three essential interventions—calling the code team, providing oxygen, and then providing epinephrine—were performed by the resident. In only five scenarios did the resident on hearing the condi-

Table 2

Times to Intervention in Pediatric Intravenous Contrast Material Reaction Scenarios

Intervention	Without-Aid Scenario*	With-Aid Scenario*	P Value
Call for code team	98	149	.08
Administer oxygen	89	40	.016†
Administer epinephrine	163	121	.21

*Data are average times to initiation of the given interventions, in seconds.

† Difference in average time to initiation of oxygen treatment between the without-resuscitation-aid (12 residents) and with-resuscitation-aid (12 residents) scenarios was significant ($P < .05$).

Table 3

Times to Two Interventions Compared between First and Second Pediatric Intravenous Contrast Material Reaction Scenarios

Intervention	First Scenario*	Second Scenario*	P Value
Call for code team	150	95	.052
Administer epinephrine	181	103	.01†

*Data are average times to initiation of given interventions, in seconds.

† Difference in average time to initiation of epinephrine treatment between the first and second scenarios was significant ($P < .05$).

Table 4

Additional Nonessential Interventions Used in Pediatric Intravenous Contrast Material Reaction Scenarios

Intervention	No. of Scenarios ($n = 38$)
Intravenous fluids	25 (66)
Diphenhydramine	15 (39)
Albuterol breathing treatment	13 (34)
Steroids	7 (18)
Trendelenburg positioning	3 (8)
Pressors	3 (8)
Histamine blockers	2 (5)

Note.—Data are numbers of scenarios in which the given additional, nonessential intervention was used. Numbers in parentheses are percentages.

tion of the simulated patient call the code team as the first intervention. The correct sequence of interventions—calling the code team, providing oxygen, and then administering epinephrine—was followed by only one resident in one scenario.

Other Interventions

Although they were not one of the three essential interventions, intravenous fluids were requested in 25 (66%) of the 38 scenarios (Table 4): in 12 scenarios when resuscitation aids were not available and in 13 scenarios when the aids were available. Among the 12 residents who ordered intravenous fluids during both scenarios, a significantly higher percentage of residents (seven [58%] of 12) administered the correct dose of fluid for the patient's size when resuscitation aids were available compared with the percentage of residents who administered the correct dose when aids were not available (one [8%] of 12, $P = .03$). Other interventions ordered by the residents during the anaphylactic scenarios included diphenhydramine, albuterol breathing treatment, steroids, Trendelenburg positioning, pressors, and histamine blockers. These interventions were not scored as appropriate or inappropriate; rather, they were just noted.

Recognition

Only five (26%) of the 19 residents stated that they were addressing a contrast material reaction. Several residents clearly did not recognize the importance of the patient's clinical status: One resident stated that the patient should be sent back to the inpatient ward, and two stated that they would call the house staff officer who was caring for the patient.

Use of Resuscitation Aids

During the 19 scenarios in which the color-coded radiology resuscitation sheets and Broselow-Luten tape were available, only six residents (32%) used both aids to measure the patient and perform precalculated interventions. Twelve residents (63%) used only one of the resuscitation aids. One resident did not use either resuscitation aid,

although both were available, and guessed (at direct questioning) at the appropriate dosing for all interventions. In addition, during the 19 scenarios in which the resuscitation aids were available, four residents (21%) measured the simulated patient incorrectly. As a result, all subsequent medication doses were inappropriate for patient size. In one instance, one resident used the wrong color-coded radiology-specific information sheet, even after accurately measuring the simulated patient and assigning the correct color code. As a result, every medication administered and intervention performed by this resident during that particular scenario was incorrect for the patient.

Discussion

In children, it has been demonstrated that the first 3–5 minutes of care during an emergency situation can prevent further health declines such as respiratory arrest or asystole (11). Therefore, there are two components of the appropriate management of emergent or life-threatening situations in children: recognition and response. A common finding in our investigation, however, was that the residents had difficulty both in recognizing the patient's condition as an anaphylactic reaction in the simulation and in treating the reaction as a life-threatening emergency. In addition, there was variability in the way the residents treated the patient's condition, which in nearly all instances was based on management of the patient's signs and symptoms—hypotension, tachycardia, and/or wheezing—and was seldom focused on addressing the underlying cause of the anaphylaxis. One resident, nearly 3 minutes into the scenario, stated, “I want to start thinking about maybe a contrast material reaction but want to hold off on epinephrine.”

The second component of the management of emergent or life-threatening situations in children is an appropriate response. Theoretically, the presence of a resuscitation tool should help ensure a more appropriate response. When a resident used the resuscitation tools,

the accurate administration of medication depended on two major factors: First, the resident had to accurately use the Broselow-Luten tape to determine the simulated patient's weight and determine the patient's color group. Second, the resident had to use the color zone to determine the appropriate predetermined vital signs, medication doses, and fluid volumes. Improper measurement of patients with use of the tape, which occurred with four residents in this investigation, is well documented and results in incorrect medication dosing (8). In addition, even after accurately measuring the simulated patient and assigning the correct color code, one resident used the wrong color-coded radiology-specific information sheet. As a result, every medication and intervention performed by this resident during that particular scenario was wrong for the patient. Thus, having the resuscitation aids available did not ensure a resident's use of them.

When the resuscitation aids were available, there was a trend toward more accurate medication dosing. Twenty-three percent of residents ordered epinephrine appropriately when the resuscitation aids were not available compared with 54% who ordered it appropriately when the aids were available ($P = .45$). There was significant improvement in the administration of intravenous fluids, which were not considered an essential intervention: 53% of residents administered the correct fluid dose when the resuscitation aids were available compared with 8% who administered the correct dose when the aids were not available ($P = .03$).

During the anaphylactic scenario, the average time to administer oxygen decreased significantly when the resuscitation aids were available compared with when they were not available. The average time to administer epinephrine also decreased, although not significantly, when the resuscitation aids were available. These findings suggest that when given a menu of possible treatments and interventions, a resident is likely to perform those interventions quickly, with a limited number of options reducing the decision time. Inter-

estingly, the time to call the code team increased, although not significantly ($P = .08$), when resuscitation aids were available. Whether the lack of a significant difference was due to the small sample size warrants further investigation. It is notable that none of the resuscitation aids available to the residents included instructions to call for assistance or to call a code team. We speculate that the presence of the resuscitation aids caused the residents to delay calling the code team because they were preoccupied with performing the series of first-responder resuscitation-stabilization interventions. The resuscitation aids may have provided the residents with more information to process during a stressful situation, or they may have given the residents a sense of confidence such that they delayed or postponed calling for assistance. We suggest that resuscitation aids for health care providers such as radiologists and radiology residents should include specific instructions on when and how to call for the code team.

The resuscitation aids may have also functioned essentially as a menu of, rather than sequential instructions for, treatment options. As one resident stated when a particular intervention was not included among the resuscitation aids, "It's not listed here—that makes me think I shouldn't give it." Sandler et al (12) conducted a survey of radiologists, presenting them with contrast material reactions of varying severity. Survey participants were provided with a list of possible medications, including some that were considered inappropriate, and while the junior radiologists performed better than the senior radiologists overall, they were more likely to request inappropriate medications than were the senior radiologists (12). The use of a menu of intervention options as a resuscitation aid is an important consideration, particularly for those with less experience: Specific instructions regarding the type and sequence of interventions should be included, and unnecessary medications should not be included.

Because each resident participated in two scenarios, a learning effect be-

tween the first and second scenarios was observed, regardless of the availability of resuscitation aids. The learning effect was demonstrated by the marginal decrease in the time to call a code team ($P = .052$) and the significant decrease in the time to administer epinephrine ($P = .01$) in the second scenario compared with that in the first scenario. These observations reinforce the finding in multiple studies that repetition and retraining are necessary for maintaining adequate cardiopulmonary resuscitation skills (13).

Our study had limitations: First, we included only a small number of radiology residents ($n = 19$). This was the maximum number of residents who could be spared from clinical responsibilities during the single observation period. Owing to a lack of power, the small sample size may have obscured the significant differences. In addition, because each resident took part in two scenarios, their actions could not be viewed as independent variables in each scenario. Having each resident take part in two scenarios resulted in a learning effect. However, we tried to minimize the learning effects by randomly assigning the residents in terms of the order of the two scenarios and by using a different-size mannequin in each scenario.

Second, during the anaphylactic scenarios, the course of the scenario would vary according to the responses and questions of the resident. By nature of our study design, each scenario could not be prospectively scripted. Because the interventions in which incomplete information was provided were not used for statistical analysis, the actual total number of interventions that could be evaluated was decreased. Similar patient simulations are currently being used by the Federation of State Medical Boards and the National Board of Medical Examiners for step 3 of the United States Medical Licensing Examination. The use of simulation as an assessment and training tool for residents has been described in the literature, and study results have revealed reductions in the time to learn specific skill sets (eg, central line placement, simulated ultra-

sonography, intraoperative bleeding scenario) and increased resident confidence during these situations (14–17). A simulation-based approach such as the one used in our study enables both evaluation of a resident's management of difficult situations without patient risk and task repetition for enhanced learning.

Third, the investigators were not blinded as to whether or not the resuscitation aids were available to the residents. We tried to minimize the effects of nonblinding by using objective data-collection criteria, such as time to intervention, and standardized medication dosing. Finally, it is difficult to estimate how closely we were able to simulate a true emergency situation. The presence of numerous observers and video cameras made for a stressful environment for the resident, and a resident may behave differently during an emergency in the middle of the night when he or she is alone. In addition, although an environment in which the facilitator provides scenario updates is somewhat artificial, in our study the facilitator was there to provide clinical updates, not unlike a nurse providing patient information such as vital signs in a true code situation. Although performance arguably could be improved in a true setting, it also could be worse owing to the stress of the situation.

In conclusion, it is evident that the level of preparedness for pediatric radiology anaphylactic emergencies is insufficient at the resident level. Although we cannot be sure that this applies to other life-threatening emergencies, such as respiratory arrest and adult contrast material reactions, it is not unreasonable to assume the same lack of preparedness for these conditions. The presence of the currently available resuscitation tools does not guarantee substantial improvement in the way a resident will respond to this anaphylactic situation. These observations suggest the need to develop a clear step-by-step resuscitation tool that includes reminders to call for assistance and provides a limited number of specific interventions necessary to stabilize a patient until assistance arrives.

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