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MEDICATION ERRORS IN PREHOSPITAL MANAGEMENT OF SIMULATED PEDIATRIC ANAPHYLAXIS

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ABSTRACT

Background. Systematic evaluation of the performances of prehospital providers during actual pediatric anaphylaxis cases has never been reported. Epinephrine medication errors in pediatric resuscitation are common, but the root causes of these errors are not fully understood. **Objective.** The primary objective of this study was to identify underlying causes of prehospital medication errors that were observed during a simulated pediatric anaphylaxis reaction. **Methods.** Two- and 4-person emergency medical services crews from eight geographically diverse agencies participated in a 20-minute simulation of a 5-year old child with progressive respiratory distress and hypotension from an anaphylactic reaction. Crews used their own equipment and drugs. A checklist-based scoring protocol was developed to help identify errors. A trained facilitator conducted a structured debriefing, supplemented by playback of video recordings, immediately after the simulated event to elicit underlying causes of errors. Errors were analyzed with mixed quantitative and qualitative methods. **Results.** One hundred forty-two subjects participated in 62 simulation sessions. Ninety-five percent of crews (59/62)

gave epinephrine, but 27 of those crews (46%) delivered the correct dose of epinephrine in an appropriate concentration and route. Twelve crews (20%) gave a dose that was ≥ 5 times the correct dose; 8 crews (14%) bolused epinephrine intravenously. Among the 55 crews who gave diphenhydramine, 4 delivered the protocol-based dose. Three crews provided an intravenous steroid, and 1 used the protocol-based dose. Underlying causes of errors were categorized into eight themes: faulty reasoning, weight estimation errors, faulty recall of medication dosages, problematic references, calculation errors, dose estimation, communication errors, and medication delivery errors. **Conclusion.** Simulation, followed by a structured debriefing, identified multiple, underlying causes of medication errors in the prehospital management of pediatric anaphylactic reactions. Sequential and synergistic errors were observed with epinephrine delivery. **Key words:** Emergency medical services; pediatric emergencies; anaphylaxis; competency assessment; simulation

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INTRODUCTION

Many prehospital care providers struggle with pediatric medication dosing. The causes of medication dosing errors are multifactorial and vary with the medication given.^{1–6} Most pediatric medication administration in the prehospital setting involves multiple steps. A few drugs, such as epinephrine, also require selection of the appropriate concentration.

The prehospital management of anaphylaxis may require three medications delivered by different routes. A retrospective review of prehospital cases of anaphylaxis in children might provide a better understanding of the causes of medication errors in the field. However, an insufficient number of cases of pediatric anaphylaxis and too many confounding variables make systematic evaluation within an emergency medical services (EMS) system difficult. Simulation of pediatric emergencies under reasonably realistic field conditions provides an alternative to direct field observation or post-event analysis.⁶

The objective of this study was to identify common and clinically significant medication errors and the underlying causes of those errors during the treatment of a standardized, simulated 5-year-old pediatric patient with anaphylaxis by prehospital providers. A

secondary objective was to report error prevention methods used by these providers.

METHODS

Study Design

We used a convergent mixed-methods study design in which quantitative (cross-sectional, observational) and qualitative data were collected simultaneously and then merged.⁷ This study was approved by the Borgess Medical Center institutional review board. Written informed consent was obtained from all subjects.

Subjects recruited for this study were licensed emergency medical technicians (EMTs), specialists, and paramedics assigned to work together by their EMS agencies as either 2- or 4-person EMS crews. Subjects were included if they met state and local medical control authority requirements for staffing an advanced life support (ALS) ambulance and were currently providing service in one of eight participating EMS agencies. All EMS agencies are required to follow the same statewide treatment protocols (see Addendum 1, available online). EMT specialists (advanced EMTs) in this state are permitted to provide intravenous therapy and perform endotracheal intubation, but they are not allowed to administer ALS medications.

The selected regions represent geographically distant and demographically diverse environments within the state of Michigan, ranging from inner-city urban to rural population densities. The agencies were committed to pediatric emergency training for their personnel. Four of the eight services were voluntarily accredited by the Commission on the Accreditation of Ambulance Services. Three of the eight participating life-support agencies require their personnel to be trained in either Pediatric Advanced Life Support (PALS) or Pediatric Emergencies for Prehospital Professionals (PEPP). These EMS crews infrequently encounter seriously ill or injured pediatric patients. According to the Michigan Emergency Records Management and Information Database, a paramedic will encounter an adult in respiratory distress once every 20 days but a child in respiratory distress once every 958 days.⁴

Sample size and sampling methods were based on established qualitative research methods. We attempted to maximize the chances of identifying underlying causes of errors.^{8–12} We used a convenience sample of subjects who were willing to participate in this project and were made available by their EMS agency. We used a theoretical sampling method in the interview process and collected data until additional interviews provided minimal new information for a theme.^{10,13,14} Based on a prior study, we estimated that 60 simulations would provide sufficient data for a qualitative analysis.⁶ Each crew was tested only once.

Study Setting

We conducted simulations in a three-compartment, mobile simulation unit described in a previous study.⁶ The walls of one compartment were covered with photo images of a child's room; another contained a stretcher, cabinets, and a photo mural of the interior of an ambulance. The control room was separated from the other compartments in the unit by one-way glass. Video cameras set at fixed angles provided digital audio/video recordings of the entire session.

Ambulances responding to the simulated call parked next to the mobile simulation unit on their agency's property. Participants responded to the simulated emergency inside the mobile simulation unit with equipment, supplies, and drugs from their own ambulances. Thus, the organization and packaging of pediatric equipment and the drugs brought to the simulation by the crews were determined by the individual agencies.

Study Protocol

Simulation

Simulations were conducted using the same methods as described in a previous study.⁶ Each crew was given an orientation to the project and the capabilities of the patient simulator. Subjects provided demographic information and answered questions about experience, level of fatigue, and confidence with pediatric emergencies on written questionnaires. Subjects were reassured that their performances during the simulation were confidential, and they were asked not to discuss the scenario with other prehospital providers. The EMS crew then participated in the 20-minute simulation.

The scenario consisted of a 5-year-old child with 1 hour of progressive respiratory distress from an anaphylactic reaction resulting from a bee sting. The patient was portrayed with a high-fidelity, programmable manikin (Pediatric 5-Year-Old Hal, Gaumard Scientific). The simulated patient in this scenario met the diagnostic criteria for anaphylaxis: acute onset of illness with skin involvement (urticaria), respiratory involvement (wheezing and shortness of breath), and hypotension ($>30\%$ decrease in systolic blood pressure).^{15,16} The child's length measured at the border of the white and blue color zone on the Broselow-Luten tape, which corresponded to an estimated weight of 18–19 kg. Hives were represented with circular, pink plastic bandages (see Figure 1). An actor portraying the child's aunt was instructed to provide all requested information, including history and physical findings that could not be simulated, but to minimize other interaction.

The simulation progressed in an identical manner for all participants. EMS crews were "dispatched" by



FIGURE 1. Simulated urticaria. “Hives” were represented by circular, plastic adhesive bandages that were painted reddish pink.

radio with the statement, “Priority One. 122 South Street, 5-year-old male patient with difficulty breathing.” Upon EMS arrival, the aunt, who had been “watching the child while his parents were out of town,” answered the door and directed the crew to the room inside the mobile simulation trailer. She reported that the child had difficulty breathing following a bee sting. The child was sitting upright, wheezing, and speaking in short sentences. Initial vital signs were BP 76/40, P 120, R 45, SpO₂ 91%. An urticarial rash was present on his arms and chest. After 3 minutes, the child became more agitated and appeared to be in marked respiratory distress. After an additional minute, the child became lethargic and bradypneic. There was no clinical evidence of airway obstruction. The actor provided planned verbal cues about changes in the child’s mental status and level of fatigue.

Crews used their own medical equipment, monitoring devices, airway equipment, intraosseous devices, drugs, and oxygen tanks. They had access to any reference tools that they carried with them, including pocket dosing or protocol guides, reference cards, and apps. The cardiac rhythm was transmitted from the manikin to the crews’ portable cardiac monitor once they attached their electrodes to the

manikin. Changes in vital signs with administration of oxygen, IV fluids, albuterol, diphenhydramine, and epinephrine were predetermined. For example, administration of epinephrine increased systolic and diastolic blood pressure by 12/7 mmHg, heart rate by 20/minute, and oxygen saturation by 2%, and decreased respiratory rate by 5/minute. Maximum and minimum changes and duration of effects were also programmed. Participants either completed their management in the child’s room or transferred the child to the simulated ambulance. If crews attempted to contact medical control for consultation, they were told that it was unavailable.

Structured Debriefing Session

A 1.5-hour structured debriefing session immediately followed the simulation. The facilitator (MWB) is a paramedic/instructor with 16 years of experience in EMS, 13 of them as a paramedic, 7 years as a paramedic instructor, 6 years in simulation education and research, and prior experience with structured debriefing. First, subjects assessed the realism of the simulation using 5-point scales and narratives. Subjects then discussed their decisions, actions, interactions, and emotional responses while watching the video recording of the simulation. The facilitator encouraged subjects to analyze and critique their own performances and identify underlying causes of errors. The facilitator initially selected debriefing questions from a list anchored to events in the scenario and also based on the performance of a particular crew, then “drilled-down” to root causes, depending on subjects’ responses (a “participant-observation” method).^{17,18} As patterns of errors emerged, the facilitator focused more on these performance problems.

Outcome Measures

An error was considered to be an incorrect decision or action, or failure to perform an expected action, without regard to the outcome, if it exposed either the simulated patient or the EMS provider to injury or potential injury. Performance was measured with an objective, checklist-based scoring protocol created for this study. EMS agencies participating in this study utilized the Michigan State EMS (Pediatric) Protocols. These protocols were developed using the *EMSC Partnership for Children/National Association of EMS Physicians Model Pediatric Protocols*.¹⁹ They were updated to reflect the 2005 International Consensus recommendations for Pediatric Basic and Advanced Life Support, although this report did not significantly change the anaphylaxis protocol.²⁰ The performance checklist for the scenario was derived from these protocols using a task analysis approach. An advisory panel of five paramedic instructor/coordinators was

selected by the investigators to independently review the scenario and sort a list of possible actions provided by the investigators into three levels of performance (*unacceptable*, *adequate*, and *optimal*). Three of the panel members were also EMS program directors, and one was also a hospital education coordinator. This process defined expected performance and the relative importance of various actions. The panel's classifications and recommendations were used to create the final performance scoring form (see Addendum 1, available online). The 63 items in the scoring protocol were scored as *completed* or *not completed*. The doses of drugs were considered correct if they were within a range of $\pm 10\%$ of the calculated dose, which was based on a weight of 18.5 kg. The lower end of the correct dosing range of epinephrine was extended to include the 0.15 mg dose in an EpiPen, Jr Auto-Injector device (Mylan Specialty L.P., Basking Ridge, NJ.) The scoring protocol was designed to standardize the process of error identification and to guide the debriefing session.

All performance scoring was completed by one investigator (MWB). By playing the role of the aunt during the scenario, she was able to observe all of the subjects during the simulations from a short distance. Her role was scripted and brief, allowing her to focus her attention on the participant's performances. This investigator/facilitator filled out checklist scoring forms during the simulations and debriefing sessions. She later verified scores and completed the scoring process upon review of field notes and all of the digitally video-recorded sessions.

The interrater reliability of the scoring form was evaluated using a random sample of 20 video recordings. Two emergency medicine residents not involved in the simulations were trained on the use of the form and scoring protocol. These two raters independently reviewed the videos and scored the crews' performances for each item on the checklist. Raters scored only those items that they were able to see on the video recordings; those items that were unobservable due to the camera angle were not scored. Interrater reliability was measured to demonstrate that the form could be used with consistency. Raters' scores did not influence the final performance scores of the facilitator.

Data Analysis

Our qualitative study methods were consistent with published guidelines for planning and reporting qualitative results using an interpretive analysis method.^{8, 18, 21, 22} We compared the qualitative data extracted from the providers' statements during interviews to direct field observations and to video recordings. This approach provides a *triangulation* of evidence and improves comprehensiveness of data collection.^{23, 24} We analyzed the observed performance errors and subjects' comments for recurrent patterns

and then systematically coded the data into major "themes" using an interactive classification method. Themes were based on clinical importance and frequency of occurrence, were derived by consensus of the two investigators, and were supported by quantitative data. Examples of data from interviews and direct representational quotes are provided to illustrate the themes.

Performance scores and error frequencies were analyzed using descriptive statistics in Excel (Microsoft, Redmond, WA.) Siegel's version of Cohen's kappa coefficient was used to evaluate the interrater agreement.

RESULTS

Characteristics of Study Subjects

One hundred forty-two subjects participated in 62 simulation sessions over a 3-month period. These crews included both on-duty and off-duty personnel from various shifts and operational subdivisions. All teams were composed of providers from the same agencies, and most worked together routinely. On the day of their participation in the study, they were assigned as partners for EMS field operations. All 23 EMTs (basic life support providers) and all 5 EMT specialists were partnered with paramedics (advanced life support providers); therefore, all crews were classified as full advanced life support units. Nine of the paramedics were licensed instructors (EMT-P/IC). All participants completed the 2-hour simulation sessions. Demographic characteristics and survey responses of subjects are listed in Table 1.

Measures of Validity and Reliability

After the simulations, participants rated the realism of the simulation and their performance as a representation of how they would manage a real case (see Table 2). Agreement between the raters on the scoring form was 78%, indicating that a substantial level of agreement is possible using this form.

Performance Scores

Crews completed an average of 37 of the 63 items (60%; range = 27–63%) on the performance checklist. Forty-three percent of subjects reported that they had not decided on roles or task assignments before entering the scene. Eighteen percent ($n = 26$) of subjects reported that "no one was the designated team leader."

Survey Results

Subjects' opinions on the effect that raising children had on their performance in this pediatric simulation are listed in Table 1.

TABLE 1. Characteristics of participating providers

	Results	Ranges
Participants		
Paramedics	<i>n</i> = 114	
EMT-specialists (AEMTs)	<i>n</i> = 5	
Emergency medical technicians	<i>n</i> = 23	
Total number of participants	<i>n</i> = 142	
Two-person crews	<i>n</i> = 53 (85%)	
Four-person crews	<i>n</i> = 9 (15%)	
Total number of crews (and simulations)	<i>n</i> = 62	
Crew configurations		
Paramedic/paramedic crews	<i>n</i> = 34	
Paramedic/EMT-specialist crews	<i>n</i> = 5	
Paramedic/EMT crews	<i>n</i> = 23	
Characteristics of all participants	<i>n</i> = 141	
Male/female ratio	75%/25%	
Length of licensure in EMS	Mean = 8.8 years	Range = 4 months–30 years
Duty hours worked prior to participation	Mean = 4.4 hours	Range = 0–30.5 hours
Level of fatigue (scale: 1–5: 1 = not fatigued, 5 = extremely fatigued)	Median = 2	Range = 1–4
Estimated number of pediatric patients managed/year	Mean = 7.8	Range = 0–100
	Median = 4	
Confidence with pediatric emergencies^a		
All participants (scale: 1–5: 1 = strongly disagree, 5 = strongly agree)	Median = 3	Range = 1–4
Effect of raising children on confidence^b		
Raised children of their own	<i>n</i> = 97 (69%)	
Improved	68 (70%)	
No effect	23 (24%)	
Worse	1 (1%)	
No answer	5 (5%)	
Did not raise children	<i>n</i> = 44 (31%)	
Improved	4 (9%)	
No effect	29 (66%)	
Worse	11 (25%)	
No answer	0	

^aParticipants rated their confidence prior to the simulation.

^bSubjects were asked, "How did the fact that you have or have not raised children affect your ability to manage this case?"

Medication Dosing

Three drugs were available by protocol and indicated in this scenario: epinephrine, diphenhydramine (Benadryl), and methylprednisolone (Solu Medrol). See Table 3 for correct medication doses and results.

Crews carried epinephrine in five forms: 1:1,000 concentration (1 mg in a 1-mL vial); 1:1,000 concentration (30 mg in a 30-mL vial); 1:10,000 concentration (1 mg in a 10-mL prefilled syringe); the EpiPen, Jr auto-injector device (unit dose of 0.15 mg); and EpiPen auto-injector device (unit dose of 0.3 mg). Because of the risk of potentially lethal arrhythmias, pulmonary edema, and cerebral hemorrhage, the administration of epinephrine intravenously for anaphylaxis "should

be reserved for profoundly hypotensive patients or patients in cardiopulmonary arrest who have failed to respond to intravenous volume replacement and several injected doses of epinephrine."^{25,26} It was considered a dangerous action in this scenario.

We observed 15% of crews deliver epinephrine intravenously from a syringe. Among the 59 providers who gave epinephrine, 14 gave it by the subcutaneous (SQ) route, 37 by the intramuscular (IM) route, and 9 intravenously (IV). One crew gave two doses—the first (correct) dose, 0.19 mg by the IM route; and the second (excessive) dose, 10 mg by IV. Forty-six percent of crews (27/59) delivered the correct dose in the correct 1:1,000 concentration by either the SQ or IM route. Twenty percent of crews (12/59) gave a dose of 1.0 mg or more of epinephrine (which is the standard dose for an adult during a cardiac arrest.) All participating crews carried diphenhydramine in a 50-mg, 1-mL vial. Methylprednisolone was available in a 125-mg, 2-mL container.

Thematic Qualitative Assessments

Based on our findings during the structured debriefing process, we constructed eight themes to explain the underlying causes of medication errors during this simulation: faulty reasoning, weight estimation errors, faulty recall of medication dosages, difficulty using

TABLE 2. Assessment of realism

Question	Median	IQR
The model provided sufficient realism for the scenario.	4	4–5
The setting and actor provided sufficient realism for the scenario.	4	4–4.5
I managed this simulated patient the same as I would manage a real patient.	4	4–5

The survey was based on a 5-point scale, ranging from "strongly disagree" to "strongly agree." The anchor for a score of 4 was "moderately agree." *n* = 141 subjects who answered surveys.

TABLE 3. Medication doses

Medications	Doses scored as correct	Routes scored as correct	n/N (%) Crews who delivered the drug	n/N (%) Crews who delivered the correct dose by the correct route	Range of doses delivered (mg)
Epinephrine	0.15–0.20 mg (0.01 mg/kg)	SQ or IM	59/62 (95)	27/59 (46)	0.1–10.0
Diphenhydramine	16–20 mg (1 mg/kg)	IM or IV	55/62 (84)	4/55 (7)	12.5–50
Methylprednisolone	34–40 mg (2 mg/kg)	IV	3/62 (5)	1/3 (33)	31.25–125

dosing references, calculation errors, dose estimation, communication errors, and medication delivery errors. During the debriefings, subjects provided their explanations, logic, and frames of reference for actions taken during the simulation. Table 4 lists a sample of explanations and quotes for each theme.

The most common error resulting from faulty reasoning was the withholding of medications despite wheezing, low blood pressure, and hypoxemia. Dosing errors resulted from incorrect weight estimates or measurements. However, 35 of the 37 crews who used the Broselow-Luten tape obtained an accurate weight. Some dosing errors resulted from faulty recall of medication dosing formulas. Confidence was not always correlated with accuracy of recall.

Providers used a variety of medication dosing guides and references, including the Broselow-Luten tape, the PediWheel First Responder (EMS Advantage), the Pedi STAT app (QxMD Medical Software), and the PALS Pocket Guide (American Heart Association). Some dosing errors resulted from the incorrect use of these guides. The pediatric medication dose references used most frequently by participants—the Broselow-Luten tape and the PediWheel—do not include epinephrine doses specifically for anaphylaxis. Five crews made the mistake of selecting the outdated, high, endotracheal (TT) dose of epinephrine for cardiopulmonary arrest on the Broselow-Luten tape. Two of these crews gave 2.1 mg of epinephrine IV (more than 10 times the acceptable dose), and one did so despite rechecking the dose in the appropriate color zone on the tape several times.

Medication dosing errors occurred when providers converted the child's weight from pounds to kilograms, calculated milligrams from a weight-based dosage formula, or converted a dose in milligrams to milliliters. Weights that are provided by parents or estimated by providers in pounds must be converted to kilograms before calculating medication doses. Many providers approximate this conversion by dividing pounds by 2. Distracted providers made mistakes even with this simple computation. Despite their hesitation about the volume of fluid being injected IM or SQ, some crews delivered ten times the acceptable dose. As providers watched the video recordings and described the steps in their reasoning and calculations,

the point at which calculation errors had been committed became apparent. An example is provided in Table 5. Some providers were unaware of the doses that they had actually delivered until reviewing the video. One had memorized a pediatric dose of epinephrine as "0.3 to 0.5 mg" and explained his rationale for using 0.3 mg (not realizing it was an excessive dose): "I didn't want to increase the heart rate too much." The provider actually delivered a 1-mg dose. Some teams committed a series of calculation errors that canceled out each other and resulted in a correct dose.

Many paramedics reported difficulty in performing computations in their heads, on smart phones, or on any available writing surface during an emergency, and they used various strategies to make calculations easier. Methods included estimation of weights, rounding of numbers, and unofficial "rules of thumb" (heuristics), such as rounding a calculation, or the "halving method" for estimating a volume that contains the desired number of milligrams. The success of these methods depends in part on the importance of precision in dosing. Repeated use of the rounding strategy sometimes produced cumulative errors.

We observed communication failures that resulted in medication dosing errors. Some participants calculated a dose, drew the medication into a syringe, and handed the syringe to a partner to deliver. Some of these providers gave incomplete information about the contents of the syringe or vague instructions to their partners about how much to deliver (Table 4).

DISCUSSION

We identified both sequential chains of events and multiple, unrelated events that resulted in medication dosing errors in the prehospital management of pediatric anaphylaxis. Six categories of errors or "themes" were cognitive in nature: mistakes in reasoning, weight estimation, and dose estimation; errors in recall and calculation; and problems using medication references or dosing guides. One category involved communication errors between team members, and one category—medication delivery—was primarily technical.

Accurate clinical assessment of infrequently encountered emergencies is challenging for EMS providers.

TABLE 4. Underlying causes of medication errors: explanations and representative quotes

-
1. **Withheld drugs or IV fluids based on faulty reasoning:**
 - a) "Patient wasn't bad enough"
 - b) Concern that epinephrine might cause deterioration
 - c) Concern that using multiple drugs in a child is harmful
 - d) Didn't know steroids were included in their protocol
 - e) Measured blood pressure only after epinephrine delivered
 2. **Incorrect weight estimate:**
 - a) Didn't have a Broselow-Luten tape
 - b) Guessed weight on the basis of appearance
 - c) Thought patient was "too old" for Broselow-Luten tape
 - d) Thought that child couldn't be measured accurately when sitting
 - e) Estimated weight on the basis of own child's weight at same age
 3. **Faulty recall of medication dosages:**
 - a) Could not recall dose
 - b) Could not recall route
 - c) Memorized dose of epinephrine as either 0.1 mg/kg (a 10-fold dosing error), 0.3–0.5 mg, or 1 mg
 - d) Believed that doses of epinephrine, diphenhydramine, and methylprednisolone for children were the same as for adults
 - e) Believed that IV boluses of epinephrine were acceptable in anaphylaxis
 4. **Problems using dosing references:**
 - a) Used high, endotracheal dose of epinephrine (previously used for cardiopulmonary arrest) by the IV route (10-fold dosing error):
"It didn't make any sense, but it came straight from the Broselow [Luten] tape, so it couldn't be wrong."
 - b) Thought that drugs for anaphylaxis were on the Broselow-Luten tape
 - c) Tiny print on some references
 - d) Protocols and doses placed on agency website were inaccessible because website was changed or signal was lost
 5. **Calculation errors:**
 - a) Multiplied weight in pounds by 2 (instead of dividing) to convert to kilograms
 - b) Decimal point errors at various steps when making calculations
 - c) Failed to give the medication because of inability to convert concentration in vial to a volume dose
 6. **Dose estimation:**
 - a) Time pressure: "We can't take time to figure out two-fifths of a mL."
 - b) Reasoned by physiology: "Kids tolerate epi pretty well; a little extra won't hurt."
 - c) "Knowing a child's dose is half of an adult [dose], I gave half of the glass vial (0.5 mg of epinephrine)."
 - d) "Two or three extra milligrams of Benda-dryl won't make a difference."
 - e) "I was guessing. Fifty is the adult dose [of diphenhydramine]; let's give him less than that."
 - f) "I didn't know if the weight was correct, so I chose to give 50 mg. It's not a big deal [to calculate the dose precisely]."
 7. **Communication errors:**
 - a) Misinterpreted partner's weight estimate from Broselow-Luten tape as being pounds instead of kilograms
 - b) Drew two doses of a drug in the same syringe, then handed off the syringe without notifying partner of total dose
 - c) One crew member was aware of bee sting but did not inform partner, who did not know the cause of the anaphylaxis
 - d) One crew member who was delivering medications was unaware that they carried a steroid; partner knew that drug was in their medication bag but did not share the information
 8. **Medication delivery errors:**
 - a) Diluted drugs with incorrect volumes
 - b) Delivered boluses of epinephrine intravenously ($n = 9$)
 - c) Inability to control a small volume of medication in a large syringe
 - d) Misread diphenhydramine concentration (as 1 mg/mL, 5 mg/mL, or 100 mg/mL)
 - e) "I'm not comfortable giving meds [epinephrine] SQ, and I had time for an IV, so I gave it IV."
-

TABLE 5. Synergistic sequence of errors

-
- In the process of delivering two doses of epinephrine, a paramedic crew performed the following actions:
1. They correctly recalled the dose of epinephrine for anaphylaxis as 0.01 mg/kg.
 2. They measured the child's length with the Broselow-Luten tape and correctly estimated weight as 19 kg.
 3. They correctly calculated a dose of 0.19 mg using a handheld calculator and then double-checked their math.
 4. Provider A verbalized the dose as "epi-point-one-nine mils—point-one-nine milligrams."
 5. Provider A drew the correct volume (0.19 mL) from a 30-mL, 1:1,000 concentration, multidose vial and delivered the drug.
 6. They recognized inadequate improvement after the first dose and decided to give a second dose.
 7. Provider A incorrectly recalled the first dose as "0.9 mg."
 8. Provide B reminded him that the first dose "included a 1 and a 9."
 9. Both providers decided that the initial dose had been 1.9 mg (combining recall and decimal point errors).
 10. In the process of drawing this dose from the multidose vial with a 1-cc syringe, provider A realized that there was not enough space in the syringe for nearly 2 mL and switched to a 10-cc syringe.
 11. Concerned that the volume was different for the second dose, provider A looked up epinephrine in his field guide and inadvertently referenced the adult dose of 0.5 mg.
 12. Provider A misinterpreted this number as a weight-based medication dose (i.e., 0.5 mg/kg).
 13. Using 20 kg as the child's weight, provider A calculated the dose in his head as "0.5 mg/kg times 20 kg = 10 mg." (The calculation is correct, but not the dose.)
 14. Provider A drew 10 mL of epinephrine (10 mg) from the vial and delivered the second dose, which is more than 50 times greater than the correct dose.
-

Jacobsen et al. conducted an online survey of paramedics to determine their level of knowledge and confidence in the recognition and management of anaphylaxis.¹⁵ Eighty-three percent had personally cared for an adult with anaphylaxis; 98% were confident that they could recognize anaphylaxis and 97% that they could manage it. Only 46% identified epinephrine as the initial drug of choice. Although 92% described the "proper location for administering an EpiPen" (the thigh), when given a case scenario, only 12% chose this location.

Periodic retraining using simulated cases may mitigate the problem of knowledge and skill decay, though EMS agencies struggle to find sufficient time for continuing education in specialty areas such as pediatrics.²⁷ Periodic retraining with interventions that involve active participation by the learner (such as simulations) may also enhance knowledge retention.²⁸ Studies show that retention of knowledge and skills is enhanced by experience with real-life resuscitations.²⁸⁻³⁰ In our study, providers who had stressful experiences managing anaphylaxis cases or lived in an area frequented by tourists exposed to allergens were most comfortable recalling and calculating medication doses. Faulty reasoning may be circumvented by insisting that EMS providers follow established protocols rather than base decisions on their own interpretations of pathophysiology.

Medication dose calculations are dependent on accurate weight measurements. Accurate weights were obtained only with the use of the Broselow-Luten tape during this simulation. EMS agencies should consider mandating that providers obtain the weights of all children by measurement when medications are required.

Other investigators have also shown that mathematical calculations under stressful circumstances are a common source of error.^{1-3,6,31-33} Calculation skills are degraded by stress and time pressures.³⁴ Other investigators have observed frequent pediatric drug dosing errors with adverse events in the prehospital setting.^{3,35} Hoyle et al. reported dosing errors with six different EMS medications; doses were greater than 20% outside of the proper dose range in 18% of pediatric patients during transport. The most common error was in the calculation of epinephrine (61%).⁵ In a review of the literature, Eastwood et al. found that many paramedics lack the mathematical proficiency to perform basic medication dose calculations. They stated, "Conceptual errors, where the operator is unable to formulate a mathematical question from the information given, have been identified as the most common type of error amongst the paramedics investigated, indicating issues other than infrequent use of mathematical skills or inability to perform calculations while under pressure."³⁶ LeBlanc et al. found

that mathematical skills were more impaired when paramedic study subjects were under the pressure of a patient-based scenario than with a written scenario.³⁷ Our findings confirm the reports of other investigators that the most common calculation errors in pediatrics are misplacement of decimal points and tenfold errors; multiplication and division errors; and weight-based errors in which patient weight in pounds is mistakenly substituted for weight in kilograms.^{38,39}

Vilke et al. described four types of self-reported medication errors among paramedics: wrong dose, wrong route, wrong medication, and protocol errors. The authors suggested precalculated medication references that provide doses in terms of volume (mL) rather than mass (mg) as a means of preventing errors.⁴⁰ Meisel et al. recommended symptom-specific drug dosing references.⁴¹ Kupas et al. advised agencies to develop standard concentrations for medications that are mixed by EMS personnel on scene and standardized methods of mixing them that are described on a recipe card.⁴² Bernius et al. showed improvement in the accuracy of medication dose calculations by paramedics with the use of a protocol-specific pediatric code card.⁴³ The error rates in this study were lower than in ours, probably because these subjects answered questions on a written exam; they were not required to perform multistep calculations rapidly, draw up the volume of medications from vials, or make treatment decisions in stressful, simulated cases. Use of medication dosing aids that are readable, specific to symptoms, and eliminate the need for any computation through precalculated, volume-based doses might be the most effective medication error-prevention strategy in prehospital pediatric care. In our study, drug dose calculations based on dosages from a reference guide were less prone to error than those derived from memory. However, references were occasionally misread. It is important to test the usability of medication dosing aids and references before widespread adoption.

Rounding calculated medication doses to more easily delivered volumes is a reasonable strategy for medications, such as diphenhydramine or methylprednisolone, that do not require the delivery of a precise dose. Although EMS protocols in the region studied specify a diphenhydramine dose of 1 mg/kg, and paramedics are expected to follow EMS protocols, the 1- to 2-mg/kg range cited in some dosing guides is a reasonable one for anaphylaxis. Some of the dose estimation heuristics used by providers during this simulation provided medication doses in an acceptable range more rapidly than if those doses were calculated precisely. However, rounding and other dose estimation strategies produced an unacceptable rate of dosing errors for epinephrine, which has a narrower therapeutic window than the other two drugs.

Use of medication dosing guides would completely eliminate the need to estimate doses.

Some communication-related medication errors during this simulation may have been avoided during the hand-off of medications if providers had stated aloud the name of the drug and the specific amount to be given in volume-based units. If a calculation is required to determine the medication dose, the initial provider could also verbalize the mathematical computations used to arrive at the dose, allowing the second provider delivering the medication to verify the accuracy of the dose.

Some providers used techniques that would have prevented the errors committed by other crews. For example, providers reported that diluting medications to a 1 mg per 1 mL concentration made weight-based dosing calculations easier. However, if dilution volumes are not carefully chosen, the new concentration can complicate calculations. Some providers used a stopcock to transfer small doses into a smaller syringe for more accurate measurement of volumes. Future studies should test these and other error-prevention strategies that could be shared throughout the EMS system.

LIMITATIONS

Although we used a definition of anaphylaxis reported in the literature, Kane and Cone reported in 2004 that there was no standard definition of allergic reaction or anaphylaxis among state EMS agencies. They observed that states have “taken a variety of approaches to the issue of BLS use of epinephrine, with the same lack of standardization that is common throughout EMS.”^{16,44} A lack of standardization might have influenced participants’ decisions to use medications.

With simulation research, subjects are aware that they are being observed and recorded. This scrutiny may motivate them to act more cautiously to avoid errors. Conversely, subjects may have less motivation to perform well when the “patient” is not real. The majority of subjects “moderately agreed” that the realism of the scenario, the setting, and the actor was sufficiently realistic, which suggests that they were engaged in the exercise and probably performed as they would have in the field.

The actor verbally provided information about the patient according to a script, which has some potential for introducing bias. We used only one rater to score performances among crews, which may have introduced some error into the scoring process. Some investigators have found that the number of raters minimally influences the reproducibility of performance scores of simulated pediatric resuscitations.⁴⁵ It is unlikely that this limitation influenced our results because the purpose of the scoring protocol was to identify errors for further discussion during the debriefing

sessions rather than to measure performances. Facilitators can introduce bias by influencing participants’ responses during debriefings.¹⁷ We attempted to minimize this effect with structured debriefing questions and training.

Despite these limitations, this study identified medication errors that require new approaches to pediatric drug dosing and others findings that provided testable hypotheses.

CONCLUSIONS

We observed eight categories of clinically significant medication errors during the prehospital management of a standardized, simulated 5-year-old pediatric patient with anaphylaxis. Dosing errors may result from a sequence of mistakes, and they may be synergistic. Epinephrine dosing errors were common and multifactorial, and would have had potentially serious consequences in real patients. EMS officials can use these findings to develop new dosing strategies or guides that reduce the frequency of medication errors.

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SUPPLEMENTARY MATERIAL AVAILABLE ONLINE

Addendum 1—Anaphylaxis Scenario: Performance Measures

Pediatric Anaphylaxis/Allergic Reaction

Pre-Medical Control

MFR/EMT/SPECIALIST/PARAMEDIC

1. Follow **Pediatric Assessment and Treatment Protocol**.
2. Determine substance or source of exposure, remove patient from source if known and able.
3. Assist the patient in administration of their own epinephrine auto-injector, if available.

EMT/SPECIALIST

4. In cases of severe allergic reaction, wheezing or hypotension:
 - A. Administer Epinephrine Junior auto injector.

PARAMEDIC

5. If patient is symptomatic, administer diphenhydramine 1 mg/kg IM/IV/IO (maximum dose 50 mg).
6. In cases of severe allergic reaction, wheezing or hypotension:
 - A. Administer Epinephrine 1:1,000, 0.01 mg/kg (0.01 ml/kg) IM to a maximum of 0.3 mg (0.3 ml), OR via auto-injector
7. In cases of profound anaphylactic shock (near cardiac arrest):
 - A. Administer Epinephrine 1:10,000, 0.01 mg/kg (0.1 ml/kg) slow IV/IO to a maximum of 0.3 mg (3 ml).

Bronchodilator Options

☐ Albuterol 2.5 mg/3ml NS nebulized

OR

☐ Albuterol 2.5 mg/3ml NS & Ipratropium 500 mcg nebulized

Medication Options:

Prednisone

50 mg tablet PO

(Children 6 and above, if tolerated)

☐ YES ☐ NO

Methylprednisolone

2 mg/kg IV/IO,

(maximum dose 125 mg)

☐ YES ☐ NO

8. Per MCA selection, administer Albuterol nebulized **OR** Albuterol and Ipratropium nebulized if wheezing or airway constriction.
9. Administer additional Albuterol 2.5 mg/3 ml NS nebulized as needed if wheezing or airway constriction persists.
10. Per MCA Selection, if a second nebulized treatment is needed also administer Prednisone **OR** Methylprednisolone, if tolerated.

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Post-Medical Control:

1. Additional Epinephrine 1:1,000, 0.01 mg/kg (0.01 ml/kg) IM to a maximum of 0.3 mg (0.3 ml), OR via auto-injector.
2. Administer Epinephrine 1:10,000, 0.01 mg/kg (0.1 ml/kg) to a maximum of 0.3 mg (3 ml) slow IV/IO.

MCA Name
MCA Board Approval Date
MDCH Approval Date
MCA Implementation Date

Section 3-2

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