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ORIGINAL RESEARCH CONTRIBUTION

Root Causes of Errors in a Simulated Prehospital Pediatric Emergency

Richard Lammers, MD, Maria Byrwa, EMT-P, and William Fales, MD

Abstract

Objectives: Systematic evaluation of prehospital provider performance during actual resuscitations is difficult. Although prior studies reported pediatric drug-dosing mistakes and other types of management errors, the underlying causes of those errors were not investigated. The objective of this study was to identify causes of errors during a simulated, prehospital pediatric emergency.

Methods: Two-person emergency medical services (EMS) crews from five geographically diverse agencies participated in a validated simulation of an infant with altered mental status, seizures, and respiratory arrest using their own equipment and drugs. A scoring protocol was used to identify errors. A debriefing conducted by a trained facilitator immediately after the simulated event elicited root causes of active and latent errors, which were analyzed by thematic qualitative assessment methods.

Results: Forty-five crews completed the study. Clinically important themes that emerged from the data included oxygen delivery, equipment organization and use, glucose measurement, drug administration, and inappropriate cardiopulmonary resuscitation. Delay in delivery of supplemental oxygen resulted from two different automaticity errors and a 54% failure rate in using an oropharyngeal airway (OPA). Most crews struggled to locate essential pediatric equipment. Three found broken or inoperable bag/-valve/masks (BVMs), resulting in delayed ventilation. Some mistrusted their intraosseous (IO) injection gun device; others used it incorrectly. Only 51% of crews measured blood glucose; some discovered that glucometers were not stored in their sealed pediatric bags. The error rate for diazepam dosing was 47%; for midazolam, it was 60%. Underlying causes of dosing errors were found in four domains (cognitive, procedural, affective, and teamwork), and they included incorrect estimates of weight, incorrect use of the Broselow pediatric emergency tape, faulty recollection of doses, difficulty with calculations under stress, mg/kg to mg to mL conversion errors, inaccurate measurement of volumes, use of the wrong end of prefilled syringes, and failure to crosscheck doses with partners.

Conclusions: Simulation, followed immediately by facilitated debriefing, uncovered underlying causes of active cognitive, procedural, affective, and teamwork errors, latent errors, and error-producing conditions in EMS pediatric care.

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Little is known about medical errors that involve children who receive care in emergency departments (EDs), and even less is known about pediatric errors in the prehospital setting. The substrate for errors in an ED is well known. Patients are unfamiliar to health care providers; complaints are diverse; problems are complex, often serious, and sometimes emotionally charged; information is limited; interruptions are too frequent; and time pressures are always present.[1]

Children are particularly vulnerable to drug-dosing errors.[2,3] It is well known that hospital drug-dosing errors occur despite pharmacist crosschecking, automated drug dispensing, and computerized order entry. None of these ''barriers'' to drug-dosing errors exist in the prehospital setting, which increases the potential

From the Department of Emergency Medicine, Michigan State University/Kalamazoo Center for Medical Studies, Kalamazoo, MI.

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Supervising Editor: Christopher Carpenter, MD.

Address for correspondence and reprints: Richard Lammers, MD; e-mail: lammers@kcms.msu.edu.

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for their occurrence. Prehospital care providers face the same challenges as providers in hospitals, with less support and sometimes in hostile settings.

The frequency of paramedic encounters with children who are seriously ill or injured is extremely low.[4] Paramedics often report that limited clinical experience is the reason they lack confidence in caring for pediatric patients.[5] Retention of knowledge and medical skills by emergency medical services (EMS) providers has been correlated with frequency of use.[6,7] For example, as pediatric airway skills decline, errors increase, even when confidence persists.[8]

Systematic evaluation of provider performance during actual resuscitations is very difficult. Simulations have provided a viable alternative.[4,9] When performance is assessed with simulations, errors become more visible. In a previous study, we observed that paramedic performance errors during three simulated pediatric emergencies occurred more frequently than anticipated.[4] The errors directly observed during the simulations may not have been identified by instructors, medical directors, or quality improvement managers if they had occurred during actual pediatric prehospital emergencies. Although types of drug-dosing and other pediatric management errors were cataloged in this study, the underlying causes of those errors were not investigated.

The objective of this study was to determine the most common, underlying causes of clinically significant errors committed by teams of prehospital providers, and associated error-producing conditions, during a standardized, simulated pediatric emergency through a process of facilitated debriefing/modified root cause analysis that was conducted immediately after the simulated event.

METHODS

Study Design

In this study, we used a combination of quantitative (cross-sectional, observational) and qualitative research methods. We followed published guidelines for planning and reporting the qualitative results of this study.[10,11] We explored qualitative research questions using the content analysis approach, in which data are systematically organized into a structured format or "themes."[10]

Study Setting and Population

This study was approved by the Borgess Medical Center Institutional Review Board and the State of Michigan EMS Institutional Review Board. Consent was obtained from all subjects.

Subjects recruited for this study were prehospital care providers who were licensed emergency medical technicians (EMTs) and/or paramedics assigned together as EMS crews and staffing advanced life support (ALS) ambulances. They were drawn from three geographically distant and demographically diverse regions within the state of Michigan (Figure 1, Table 1). Subjects were eligible for inclusion if they met state and local medical control authority requirements for staffing an ALS ambulance. Most of the EMS teams were drawn from on-duty EMS crews to study providers in the physical condition in which they might respond to an actual incident within their service area.

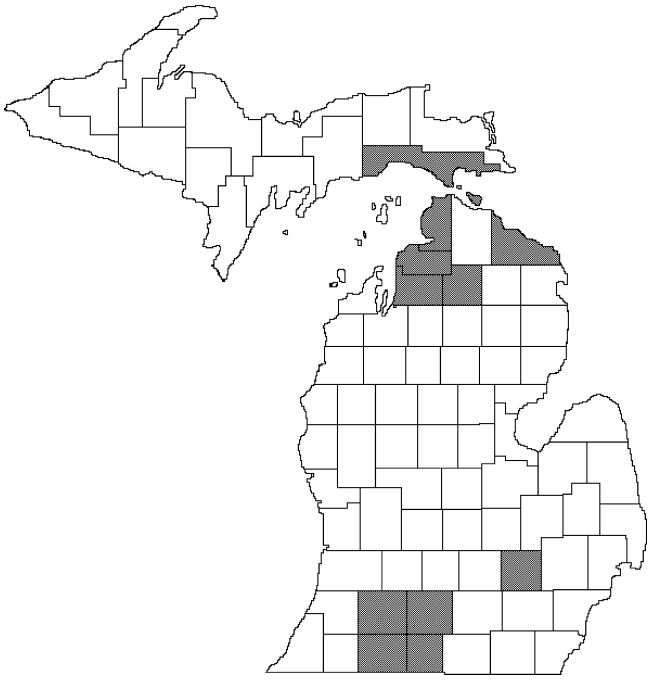

Figure 1. Sources of study subjects.

Table 1
Characteristics of the Regions of Participating Paramedics

2007 Statistics	Northern Region	Southern Region	Total
Number of agencies	2	3	5
Total population base	130,718	490,483	621,201
Population <5 years old	6,773	32,245	39,018
Total number of paramedics	64	129	193
Full-time paramedics	45	113	158
Part-time paramedics	19	16	35
Total number of calls	6,575	42,663	49,238
Number of transports	8,352	33,118	41,470
Number of patients <5 years old	119	738	857

The five participating EMS agencies collectively serve a diverse population ranging from inner city urban to rural, representing 9% of the state's population. These agencies were selected because of their past history of collaboration on projects of this nature, their commitment to pediatric emergency training for their personnel, and their general high regard within the Michigan EMS community. All four agencies in the southern and central regions are nationally accredited through the Commission on Accreditation of Ambulance Services. Three of the five participating agencies required their personnel to be trained in either Pediatric Advanced Life Support (PALS) or Pediatric Emergencies for Prehospital Professionals (PEPP). All participants completed the 2-hour sessions.

Study Protocol

Simulations were conducted in a "mobile simulation unit" (MSU) designed specifically for this project. The MSU consisted of a 24-foot trailer divided into three compartments: a control room, a simulated child's room, and a simulated interior of an ambulance (see Data Supplements S1 and S2, available as supporting information in the online version of this paper). The control room was divided from the other compartments by one-way glass through which the simulation could be observed. The other two compartments were divided by a curtain with photo images of the room and the ambulance on each side. Three video cameras were set at fixed angles in two compartments for digital audio/video recording of the entire session. The MSU standardized and approximated the EMS environment.

We stationed the MSU within the community of participating paramedics. Crews parked their ambulances alongside the unit and, to avoid interruptions, temporarily took themselves "out of service." Crews responded with all needed equipment and drugs from their own ambulances to the simulated scene inside the MSU. Since crews used their own materials, the organization and packaging of pediatric equipment and drugs used during the simulation were identical to what they use in actual practice and specific to their individual agencies.

Sample size determination in this qualitative study was based on the goal of minimizing the chances of "discovery failure." We used a "judgment sampling" method for selection of EMS agencies that was based on geographic diversity (urban, suburban, and rural). We used a convenience sample of subjects who were willing to participate in this project and available from each agency. Finally, we used a "theoretic sampling" method (collection of data until data saturation for each theme was achieved) for interviews of subjects.[12]

Taxonomy. We modified error taxonomies that have been described by other authors.[13–26] In this project, an *"error"* was considered to be an incorrect decision or action, without regard to the outcome. An *"adverse event"* was an injury caused by prehospital provider management. An *"unpreventable adverse outcome"* describes an undesirable but unavoidable consequence of an illness or injury. A reasonable and appropriate decision or action that leads to an unpreventable adverse outcome should not be classified as an error. A *"bad outcome"* can result from either an error or an unavoidable progression of disease or from both. In this study, all unpreventable adverse outcomes were predetermined during scenario design, and therefore, they were not considered errors. However, an inappropriate or incorrect decision or action that did not result in an adverse event was still counted as an error if it exposed the patient to potential injury.

We designed this study to uncover both active and latent errors. *"Active errors"* are the immediate results of mistakes by the EMS providers during patient management. *"Latent errors"* are embedded in the design of equipment, a process, or the "system" in which providers work and are "waiting to happen." Contributory factors for errors (also known as *"error-producing conditions"*) include conditions such as excessive workload; fatigue; inadequate knowledge, skill, or experience; equipment failure; equipment design limitations; patient factors; team communication failures; environmental factors; and system factors.[23]

Scenario. We created a simulation scenario with three objectives: 1) replicate a plausible pediatric emergency condition, 2) present realistic performance challenges, and 3) potentially elicit error-prone behaviors and skills. The scenario consisted of a 6-month-old infant with a shaken baby syndrome, resulting in a decreased level of consciousness, followed by a seizure and respiratory arrest caused by a traumatic intracranial hemorrhage. Scenarios and actor dialogs were carefully scripted.

The EMS crew was dispatched by radio for a "Priority 1 (9-1-1) call for a 6-month-old infant with decreased level of consciousness." On arrival, the crew had to deal with parents, played by actors, who were quarreling, unhelpful, suspicious, and sometimes hostile. The mother stated that the child had been fussy all day, and she felt she had done everything to make him stop crying. For the past hour, the child had been "difficult to wake up and acting strangely." The infant was portrayed with a high-fidelity, programmable mannequin (SimBaby; Laerdal Corp., Wappingers Falls, NY). Important physical findings in this scenario included a lethargic cry on initial stimulation, a full fontanelle, pupils that were equal but sluggishly reactive (provided by report), palpable pulses, chest rise with respirations, and thumbprint-size bruising on both arms of the child. The scenario progressed through three phases: altered mental status, seizure, and respiratory arrest. In general, subjects were expected to perform the following assessment and treatment in the time allotted: 1) identify altered mental status and potential for head and neck injury through assessment, 2) use the Broselow tape to determine the infant's weight, 3) provide supplemental oxygen, 4) check blood glucose level, 5) stop the seizure with the correct dose and route of an anticonvulsant medication, 6) identify respiratory depression, 7) maintain oxygenation by assisting ventilations and using appropriate airway devices, and 8) calm and reassure the mother while avoiding accusations.

Outcome Measures. We tracked performance with an objective, checklist-based "performance scoring protocol" created for this study. The EMS agencies participating in this study currently use the Michigan State Model EMS (Pediatric) Protocols or protocols consistent with the State Model Protocols. The State Model (Pediatric) Protocols were based on the *EMSC Partnership for Children/National Association of EMS Physicians Model Pediatric Protocols*[27] and updated to reflect the most current (2005) pediatric resuscitation guidelines published by the American Heart Association.[28] Performance standards for the scenario in this study were developed from these protocols using a previously described task analysis approach.[4]

Validations. To validate the content of the performance scoring protocol, a panel of five EMS regional program directors and instructors (not associated with the study but selected by the investigators) individually reviewed

the scoring protocol. Panelists sorted a list of potential actions provided by the investigators into three levels of performance (''unacceptable,'' ''adequate,'' and ''optimal'') to produce the final, consensus-based checklist performance scoring form[29] (Data Supplement S3, available as supporting information in the online version of this paper). Items on the checklist were presented as single, ''action verb–noun'' items that were scored as ''done'' or ''not done.'' Checklist items were dichotomous and not weighted. Some items assessed timeliness of actions; none assessed sequence of actions. Finally, a global assessment form with 13 assessment items, each with seven-point, anchored scale (with ranges from ''unacceptable'' to ''superior'' and guidelines for scores of ''1,'' ''4,'' and ''7''), was developed as an additional but secondary, overall measure of performance, designed to capture elements of performance not reflected in the checklist. The checklist served three functions: 1) to identify errors, as well as substandard and superior performances; 2) to guide the subsequent debriefing session; and 3) to generate individual performance scores.

EMS experts reviewed the scenario for realism (face validity) and content validity. After pilot testing and revising the scenario and scoring protocol, we demonstrated construct validity by comparing the performances of nine paramedic students who had no field experience with 10 EM residents who had completed a pediatric intensive care rotation. Performance scores from the checklist-based scoring protocol were significantly different between these two groups (Mann-Whitney U-test; $p < 0.01$; data not shown).

The reliability of the scoring forms for this scenario was assessed by raters not involved in the simulations. A paramedic instructor/coordinator and an emergency medicine resident were trained in the use of the checklist and the global assessment forms. They independently scored a random sample of the same 10 recordings. Inter-rater reliability with the checklist performance scoring form was calculated using the exact agreement method and Cohen's kappa statistic. Inter-rater reliability with the global assessment form was analyzed using Krippendorff's alpha for interval data. The standard for a ''very good'' level of agreement for both methods is >80%. Their scores were not compared with the facilitator's scores or used in the final performance scores because the facilitator had the advantage of direct, close observation in addition to the recordings.

Facilitated Debriefing. We designed a facilitated debriefing exercise that allowed subjects and the facilitator together to identify root causes of errors immediately after the simulations. The process described by Taylor-Adams and Vincent,[30] and on the Department of Veterans Affairs National Center for Patient Safety website,[31] was modified for this study. Our interactive exercise consisted of written questions, interviews, and facilitated discussion that encouraged self-analysis of performance. The objectives of these exercises were to: 1) identify problems (including active and latent errors and ''close calls'') encountered during the simulation, 2) determine if the problems had any adverse outcomes, 3) look for underlying causes of errors and contributory factors, 4) suggest solutions that would prevent the problem in the future, and 5) identify those factors that enhanced performance or provided more effective management of the case.

The investigator responsible for facilitating the debriefing sessions in the field (MB) is a female paramedic/instructor with 14 years of experience in EMS and 11 of them as a paramedic. She received training on interviewing techniques and root cause analysis for this project by members of the Department of Psychology, Western Michigan University (Kalamazoo, MI). This facilitator practiced debriefing skills through role-playing and during pilot tests of the exercises. The psychologists provided corrective feedback to the facilitator during the practice sessions and after reviewing a sample of the digital recordings obtained during the study. The facilitator was not associated with the employers of any of the subjects, had no influence on work-related performance evaluations, and had no prior knowledge of subjects' skills.

The facilitator was given sample debriefing questions and lines of inquiry to pursue that were determined by the performance of a particular crew. These items were anchored to events in the scenario and focused on four domains: cognitive, procedural, affective, and teamwork.[14] For example, cognitive questions included sources of specific knowledge, frames of reference, decision-making, prioritization, planning, calculations, methods of overcoming obstacles, and monitoring for changes and complications. Procedural questions evaluated observable actions such as use of equipment or delivery of drugs. Affective questions considered how subjects handled emotional situations, if their methods were effective, and how they controlled their emotional responses to stress and to the hostile mother. Teamwork questions evaluated issues such as division of labor, assignment of responsibility, communication, and cross-checking. The task loads represented by each of these domains varied during the three phases of the scenario. Errors and error-producing conditions were investigated using both structured questions initially and a ''drill-down'' method, depending on subjects' responses.[32]

Simulation Protocol. The combined simulation and debriefing session was 2 hours in duration. Each crew was given a scripted overview of the project and a briefing on the session schedule. Subjects provided demographic information and answered questions about experience level and confidence with pediatric emergencies on a questionnaire. They also rated their level of fatigue on a scale of 1 (not fatigued) to 5 (extremely fatigued) prior to starting the simulation. The capabilities of the patient simulator and important elements in the simulation environment were described and demonstrated. Subjects were reassured that their performances during the simulation were confidential and would not be reflected in future performance evaluations or trigger remediation.

Subjects were asked to not discuss the scenario with other prehospital providers who were eligible to participate in the simulation. After the introduction, the two-person EMS crew experienced the patient simulation scenario. Crews used their own medical equipment,

including monitoring devices, airway equipment, intraosseous (IO) devices, drugs, and oxygen tanks. Information about the infant's appearance that could not be conveyed by the mannequin was provided over a handheld radio by simulation field staff in the control room. Physiologic changes and responses to drugs were preprogrammed and not modified during the scenarios. The flat-screen patient monitor that is connected by cables to the mannequin (and shows cardiac rhythm, blood pressure, oxygen saturation, and other physiologic parameters) was not visible to the subjects. The cardiac rhythm was transmitted from the mannequin to the crews' own portable cardiac monitor only if subjects attached their electrodes to the mannequin. Subjects completed their management in the infant's room or transferred to the simulated ambulance as desired. If the crew attempted to contact a direct medical oversight physician for advice, they were told that radio contact failed. Simulations lasted precisely 20 minutes.

Upon completion of the simulation, subjects answered a brief set of written questions. A short, unstructured debriefing allowed subjects to react to the experience and emotionally decompress. Subjects then underwent the facilitated debriefing process in the simulation unit, reflecting on and self-critiquing their performances while watching the digital recording of the simulation. They were encouraged to analyze their decisions, actions, interactions, and emotional responses. At the completion of the session, the facilitator summarized the experience, and the participants assessed (in writing) the realism of the simulation and the strengths and weaknesses of their performances. Each crew was tested only once.

One investigator (MB) completed all performance scoring in a standardized manner. Since this person played the role of the mother during the scenario, she was able to observe all of the subjects during the simulations from a distance of only 1 to 2 m. The investigator/facilitator filled out the checklist scoring forms during the simulations and debriefing sessions, and she completed them upon review of field notes and all of the digitally recorded sessions. This investigator reviewed all recordings twice—once during the debriefing and once after the session—to verify the accuracy of scoring. If the investigator was uncertain of the volume of a medication that was delivered during the scenario, she examined the syringe during the debriefing. A trained paramedic instructor/coordinator later independently reviewed and scored all of the recorded sessions. The investigator reviewed the checklists of this second rater, replayed portions of recordings when there were differences in scores, and resolved all discrepancies. Time-to-task performance was extracted from the recordings. Global assessment forms were completed after viewing the digital videos.

Data Analysis

Both quantitative and qualitative methods were used to analyze data. Content analysis data (i.e., percentage of respondents identifying specific classes of errors or underlying contributing factors) and performance scores were analyzed using descriptive statistics, including means, medians, ranges, and interquartile ranges (IQRs).

Data on performance errors and error-producing conditions were organized into "themes" that emerged from performance and subjects' comments over time. The number of themes was narrowed on the basis of frequency and importance of the concept. Examples of data from interviews (including quotes) are provided to illustrate each of the themes.[10,11] Selection of themes was supported by quantitative data and subjects' responses on the final questionnaire, and a "credibility check" of theme categories[11] was provided by a second investigator. Simulations were continued until data saturation was reached in each theme.

RESULTS

Demographics

We conducted 45 simulation sessions with 90 subjects over a 6-month period. Crew configurations were either two-person EMT/paramedic (n = 20), paramedic/paramedic (n = 20), or paramedic/specialist (n = 5) teams. These crews were representative of various shifts and operational subdivisions, and they included both on-duty and off-duty personnel.

Sixty-seven percent of subjects were male; 33% were female. Sixty percent had raised children of their own. Their average length of licensure in EMS was 7.2 years (range = 0.1 to 26 years). The average number of hours per month worked in EMS was 172 (range = 24 to 320 hours). Subjects estimated that the number of pediatric cases (age < 14 years) they managed each year was 6.4 (range = 0 to 50), and the estimated number of pediatric cardiac arrests in their careers was 2.7 (range = 0 to 25). The average number of duty hours worked by subjects prior to participation in the simulation was 5.9 (range = 0 to 30 hours). The length of time crews had worked as partners in the field ranged from 1 day to 20 years. The subjects' median level of fatigue was 2 (range = 1–3, except for one "5"). In response to the statement, "I am confident in my ability to treat pediatric emergencies" (1 = strongly disagree; 5 = strongly agree), the median score was 3 (range = 1 to 5).

Inter-rater Reliability Assessment

The overall percentage of agreement on scores between the two raters using the checklist performance scoring form was 84% (exact agreement method; $\kappa = 0.82$. Agreement on the global assessment form was 47%.

Performance Scores

Crews completed an average of 47 of the 76 scorable items ("adequate" plus "optimal" actions) on the performance checklist (median = 63%; range = 43% to 76%; IQR = 57% to 66%).

Thematic Qualitative Assessments

Five clinically important themes emerged from our observations of crews' performances and from the debriefing sessions: oxygen delivery, equipment organization and use, glucose measurement, drug administration, and inappropriate cardiopulmonary resuscitation (CPR).

Oxygen Delivery

In the majority of the simulation sessions, delivery of supplemental oxygen was delayed for more than 1 minute after respiratory arrest. Subjects reported common reasons for this error (when possible, an error classification is included in brackets).

1. Crews did not bring the adult cot (stretcher) from the ambulance to the child's location. The oxygen tank is usually stored on that cot. When the need for oxygen was apparent, one of the paramedics had to return to the ambulance to retrieve the tank [an automaticity error].
2. Other crews expect medical first responders (police and fire rescuers) to bring this item to the scene (medical first responders were not involved in this simulation [an automaticity error]).
3. Some could not find pediatric airway equipment (such as masks) in their equipment bag [a procedural error].
4. Fifty-four percent of crews did not use an oropharyngeal airway (OPA) with bag/valve/mask (BVM) ventilations during respiratory arrest, and some failed to achieve effective ventilations as a result. Many crews attributed this oversight to ''out of sight, out of mind'' [a cognitive error of omission]. Comments included: ''I taught BLS airway class 2 weeks ago and still forgot (to use an OPA)!''; ''Stop the seizure, then put O_2 on. They're not getting O_2 anyway (while seizing).''

Equipment Organization and Use

We found a wide variety of pediatric equipment organization and storage strategies among the participating agencies. Some agencies have pediatric-specific bags, while others dedicate a section of their adult bag for pediatric equipment. Some subjects described their method of locating equipment as a process of ''digging or dumping.''

Pediatric equipment that was integrated into the adult bag during the scenario was usually forced into a small space or compartment. There were several instances of broken pediatric equipment, including BVMs, as a consequence of this storage configuration. This broken equipment was destined for use in actual emergencies had it not been expended during the simulation. Subjects reported that this problem went unrecognized (until attempting to ventilate the mannequin) because this equipment is locked up, rarely used, and not checked. One subject explained: ''The peds bag is sealed. We only get in the bag when the saline expires.''

Broken equipment that delayed BVM ventilation was a latent error resulting from an inadequate storage system and lack of protocols to check equipment. The ''error-producing condition'' in this case was external to the paramedics.

Regardless of the organization of the pediatric equipment or the storage configuration, most crews were unfamiliar with the location and contents of the pediatric equipment section or bag from their own agency. Various error-producing conditions were discovered that suggest a combination of latent, system-based errors occurred:

1. EMS crews do not use pediatric equipment on a regular basis because of the low frequency of pediatric calls.
2. Agencies ''tag'' equipment bags and sections for stocking accountability purposes, and a bag or section can only be opened when needed during a call. Crews are not allowed to routinely check the functioning of pediatric equipment.
3. Agencies that store pediatric equipment in their adult bags are not able to fit all necessary pediatric equipment (e.g., pediatric-size oxygen masks) into it.
4. Agencies that carry a separate, pediatric equipment bag do not carry all the equipment needed for some pediatric emergencies (e.g., glucometers and IV fluids).

By design, subjects were told that attempts at IV access were unsuccessful. Seventy-three percent of crews attempted the alternative, which is an IO line, and the remaining crews gave medications by the intramuscular or rectal route. Types of IO insertion devices varied among agencies. No problems were observed with IO insertion using the standard, manual IO needle (Jamshidi needle; Cardinal Health) or the EZ IO drill (Vidacare). Some crews had an IO device, the Bone Injection Gun (B.I.G., Waismed), that shoots the needle into the bone. Many were unfamiliar with it, lacked confidence in using it, or because of previous experience with the device, were fearful that the gun was too powerful for pediatric patients. Most crews who used the B.I.G. reported insertion problems. The needle was inserted at an inadequate depth because subjects set the gauge to a shallow depth, didn't press it against the skin firmly enough to assist with penetration, or found that the spring action caused the needle to bounce back and either fall out or fail to infuse. Some had difficulty disengaging the device from the needle once it was inserted. Most crews with access to the B.I.G. opted to use a backup device (the standard manual IO needle).

Eighty percent of crews used the Broselow Pediatric Emergency Tape (Armstrong Medical) correctly to estimate the weight of the infant. Two crews (4%) used it incorrectly by measuring from the wrong end, and one measured in the newborn zone [both procedural errors]. The remaining 13% of crews guessed the weight of the infant or accepted the mother's vague estimate [cognitive errors]. All weight estimates without the tape were incorrect. Some admitted that they forgot to use it. Rationales included: ''I never used the Broselow Tape before. I asked for it, knew what was on it, but never trained on it.''; ''EMT CE (continuing education) for peds is never (provided)!''

Glucose Measurement

The scenario involved an infant with an altered level of consciousness and a subsequent seizure; therefore, measuring a blood glucose level was an expected action. Only 51% of the crews performed this test. Seven of the 23 tested the glucose level more than

15 minutes into the scenario. Some said they ''didn't think to do the test'' [a cognitive error], but others found that glucometers were not stored in the sealed pediatric bag and had to run out to the ambulance to retrieve one from the adult bag [a latent error].

Drug Administration

Delivery of the correct, EMS protocol-based dose (with a ± 10% margin of error) of an anticonvulsant drug was an expected action. We recorded the mg/kg dose selected, the mg dose calculated, and the mL (volume) of drug delivered.

Thirteen crews gave midazolam by intramuscular injection; six of the 13 (46%) gave the correct dose. Seven crews gave midazolam by IO infusion; three of them (43%) gave the correct dose. Two crews administered midazolam via the rectal route (outside of their EMS protocol). Overall, there was a 60% active error rate for midazolam dosing. One crew spent too much time trying to calculate the dose and ran out of time before delivering any anticonvulsant.

Twelve crews gave diazepam by IO infusion; nine of the 12 (75%) gave the correct dose. Ten crews gave diazepam by the rectal route; five (50%) gave the correct dose. Overall, there was a 47% active error rate for diazepam dosing. Explanations included: ''I never used Valium; all my patients have been postictal.''; ''I didn't know the dose; I fumbled through the field guide.''; ''Valium comes 10 mgs in 2 mL; so 5 mgs is 1 mL; 2.5 mgs is 0.5 mL; 1.25 mgs is 0.25 mL. I needed 0.3 mgs. I keep halving it (the dose and volume) until (the desired dose) it's close.''

Problems with pediatric drug dosing were attributed by some subjects to poor math skills or faulty recall of drug doses [cognitive errors]. However, debriefing revealed additional, underlying causes of dosing errors within cognitive, procedural, affective, and teamwork domains (see Figure 2):

1. Protocols call for different doses depending on routes of delivery, which requires paramedics to memorize twice as many doses [a latent error producing an active cognitive error].

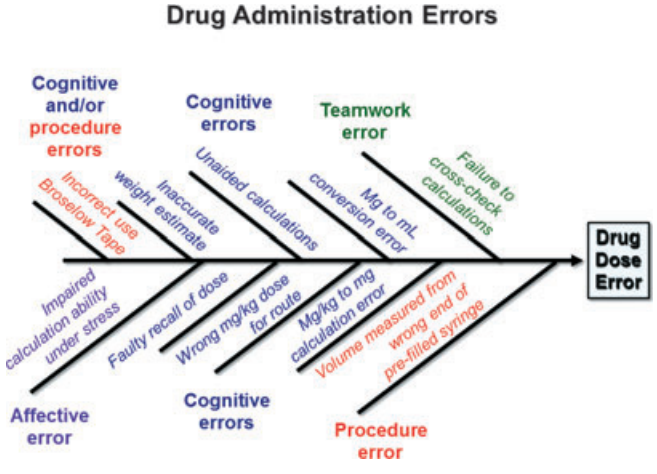

Figure 2. Drug administration errors. Fishbone diagram showing how a variety of factors, individually or combined, can result in a bad outcome.

2. Incorrect weight estimates were used to calculate drug doses [cognitive errors and, when the Broselow tape was used incorrectly, a procedural error].
3. Some admitted difficulty with calculations under stress [a combined cognitive and affective error]. None of the participants used calculation aids, such as a pocket calculator. However, some had preprinted, weight-based, drug dose cards.
4. Some subjects made calculation errors when converting a mg/kg dose to mg and others when converting mg to mL [cognitive errors].
5. Subjects explained that the measurements on the prefilled syringe of diazepam are opposite in direction from those on the more familiar prefilled syringe of epinephrine. The scale on the diazepam syringe measures the volume of drug remaining, whereas the syringe on the epinephrine syringe measures the volume delivered. The plunger in the diazepam syringe is pushed in, toward the needle, and on the epinephrine syringe it is pushed away from the needle. Subjects felt that the variation in syringe designs was a source of confusion and drug dosing errors [a latent error producing a procedure-based error].
6. Some confused the milliliter increments on the sides of syringes with milligrams [a cognitive error]. The concentration of diazepam is 10 mg/2 mL in the syringes that were used, and increments are measured in mL. Epinephrine is also packaged in a prefilled syringe, but the concentration is 1 mg in 10 mL, and the syringe is measured in both milligrams and milliliters.
7. Sixty-four percent did not crosscheck calculations or doses with their partners [a teamwork error]. Comments during the debriefings included:
   ''I don't know peds doses for the life of me. We don't do it enough.''
   ''Meds are not pediatric friendly.''

Inappropriate CPR

The infant maintained a pulse throughout the scenario. The lowest heart rate was 90 beats/min. We observed the following active errors:

1. Four crews did not feel a pulse (although it was present) and initiated chest compressions [a procedural error].
2. One crew started chest compressions when the heart rate dropped below 100 beats/min. The rationale provided initially for this cognitive error was simply that ''the heart rate was less than 100.'' Upon further questioning, the crew believed that there was a specific prehospital protocol for this response (none exists). They also reasoned that ''if the appropriate rate of chest compressions in children is 100 per minute, then chest compressions should be started if the heart rate falls below that level'' [a heuristic or cognitive error]. One subject described a rhythm interpretation that led to the decision to begin chest compressions: ''It was sinus tach (tachycardia) and (it) widened like it was going to go into v-tach (ventricular tachycardia).''

DISCUSSION

This project represents one of the first prospective studies to look critically at errors and contributory factors in the care of ill and injured children in the prehospital environment. The EMS agencies and their personnel selected for this study are representative of many EMS systems throughout the nation.

The traditional approach to investigations of adverse outcomes in health care has been to blame a bad outcome on the person ''last holding the scalpel'' or ''administering the drug.'' Punishing or remediating an individual for a ''human error'' often guarantees that the adverse event will occur again when different people are involved.[14] Investigators who have conducted more extensive analyses have found chains of preceding events, or convergence of contributory factors within complex systems, that produced adverse events.[33] ''Error-producing conditions'' are intrinsic features of the environment that contribute to mistakes. In EMS, these factors include time pressures, diagnostic uncertainty, high cognitive load, limited information, and hazardous conditions.[21] Effective remediation of a problem depends on the ability of paramedic instructors or EMS medical directors to uncover not only the proximate cause, but also the underlying, root cause of an error.

Root cause analysis is a qualitative but rigorous method of error investigation that has been used to determine why an error occurred. All of the immediate events and the contributory factors are connected chronologically through structured interviews, document review, and field observation.[34] Root cause analysis has methodologic limitations. Analysis of narratives and clinical cases may be limited by problems that are common to retrospective self-reports, including selective reminiscence, embellishment, exaggeration, inadequate detail, and lack of statistical validity.[14] Conducting root cause analysis on video-recorded, simulated incidents can eliminate most of these problems.

This study demonstrates the value of simulation for discovering unanticipated errors and previously unrecognized, error-producing conditions in prehospital care. When designing simulations for the purpose of studying errors, it is important to re-create through simulation many of the conditions in which EMS providers work. A paramedic who can accurately convert milligrams per kilogram into milliliters of drug in a classroom setting may not be able to reproduce that performance during a simulation in which an actress mother is shouting, the paramedic partner is asking questions, the environment is becoming noisier, and the urgency of the situation is escalating.[35]

Although cognitive errors may be the most common type of active error in health care, they are difficult to examine retrospectively.[14] Procedural errors, or technical mistakes, are the most easily defined and measured type of performance errors. Affective errors, which may result from transference and attribution phenomena, can occur during interactions with patients and families.[14] Prehospital care providers may be more vulnerable to affective errors because life-threatening pediatric emergencies are almost always emotionally charged situations. Affective errors may be studied more efficiently through simulation. Errors associated with team interactions are also difficult to evaluate, although measurement systems have been described.[36]

Drug-dosing errors are commonly reported, preventable, adverse events in pediatric care. The underlying causes of those errors during the simulated, prehospital pediatric emergencies in this project included more than just miscalculation. Stressful conditions cause affective errors. Calculation under stress is prone to error, and calculations themselves cause stress. Many errors could be avoided by providing cognitive or ''memory'' aids (e.g., drug dosing cards) or by avoiding calculations during resuscitations altogether. Unfortunately, these simple remedies would not eliminate all of the factors that contribute to drug dosing errors. Nelson et al.[37] found that 85% of pediatric residents used cognitive aids to assist in managing simulated pediatric cardiopulmonary arrests. However, 25% of those who used them chose the incorrect treatment algorithm from these aids.[37] Proper design of cognitive aids is important if they are to be effective in reducing errors.

We found that various cognitive, procedural, and teamwork error-producing conditions can individually or synergistically trigger drug dosing errors. For example, most of the incorrect weight estimations were errors of omission or commission by EMS crews. The confusing designs of prefilled syringes were latent errors external to those providers (since the providers were not responsible for these designs). The underlying causes of a resultant adverse outcome—the delivery of a wrong drug dose—are seldom observed during an actual resuscitation, and not easily identified during delayed, retrospective analysis of paperwork.

Through facilitated self-analysis and immediate review of video recordings, EMS crews were able to describe sequences of events or conditions that led to delays, failure to follow protocols, or dosing errors. EMS crews could provide accurate and detailed rationales for some of their decisions and actions because the event was fresh in their memories. For example, the inability of crews to periodically review the contents and organization of their sealed pediatric bags led to delays in oxygen administration and evaluation of blood glucose. It is possible that their frustration increased their ''affective load'' and impaired their calculation skills. The facilitator was also able to identify clever methods used to overcome problems—approaches that seemed routine to the provider but were not part of training and were not observed with other crews. As a result of this study, the following recommendations were sent to the participating EMS agencies:

1. Store portable oxygen tanks with other equipment that is carried to the scene of a pediatric patient.
2. Assure that essential patient care equipment, such as glucometers and IV fluid, is included in pediatric-specific bags.
3. Require all personnel to inspect pediatric equipment on a regular basis.
4. Perform a functional inspection of vital equipment that is susceptible to breakage (i.e., BVMs).

5. Label sealed compartments in pediatric bags.
6. Tape OPAs directly to BVMs.
7. Agencies that use the B.I.G. should:
   A. Provide more training,
   B. Limit the use of this device to adults and adolescents,
   C. Consider replacement with an alternative IO system.
8. Reinforce universal blood glucose assessment for altered mental status.
9. Eliminate reverse-graduated prefilled syringes (e.g., Carpoject and Monject devices).
10. Encourage drug dilutions to achieve 1:1 concentrations and easier calculations, when possible.
11. Provide ''hands-on'' continuing education on pediatric medications and drug dilutions, using syringes to draw calculated volumes of medications in the context of a simulated case, when possible.
12. Develop an EMS-specific Broselow tape consistent with state protocols.
13. Provide ongoing training on the existing Broselow tape.
14. Provide periodic competency testing on the use of medication dosing reference cards or other cognitive aids.

LIMITATIONS

It is more difficult to determine if an adequate sample size was achieved in quantitative studies. In this study, subjects were selected from only one state, but they were sampled from EMS agencies that service populations ranging from dense to sparse and from city to rural regions and from a pool of providers with a wide range of years of experience. A total of 18% to 43% (median = 28%) of each EMS agencies' crews were studied, creating a large sample from the entire population of interest.

In research using simulation, maximizing realism is a challenge. Realism in simulation is a product of the scenario, the simulator, the equipment, the environment, and other factors. The high-fidelity simulator that was used in this study provided feedback through physical and physiologic findings, and participants used drugs and equipment from their own ambulances. Subjects may have had varying degrees of comfort and familiarity with simulation or with the mannequin. Despite an orientation, some paramedics failed to feel a pulse during the scenario, which may have been a simulation artifact. Nevertheless, the scenario was shown to discriminate experienced from novice health care providers (residents vs. paramedic students).

Investigators must show that their measurement tools are reliable and valid.[38,39] The reliability of our measures of clinical performance was enhanced through a scripted orientation and instructions, standardized tasks established in advance through expert panel review and consensus, and scoring with a checklist-based protocol by the same examiner and verified by review of recordings. Inter-rater reliability was acceptable using the checklist method, but not the global assessment method. Possible explanations include the greater number of options on the seven-point scales on the global assessment form compared to the dichotomous choices on a checklist, overlapping definitions in the guidelines for anchors, and the subjective nature of global assessment.

As with any qualitative study, the values of the investigators affect the interpretation of the findings. However, the conclusions were reached through the consensus of all three investigators—a paramedic/instructor, an EMS medical director, and an emergency physician. In thematic analysis, conclusions emerge from both the research design and from the narratives of the subjects.

CONCLUSIONS

Cognitive, procedural, affective, teamwork errors, and error-producing conditions were identified during a simulated, prehospital pediatric emergency. Errors were categorized into five general themes: oxygen delivery, equipment organization and use, glucose measurement, drug administration, and inappropriate CPR. Simulation that reproduces prehospital conditions, followed by facilitated debriefing, is an effective tool for identifying underlying causes of active and latent errors in EMS pediatric care.

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References

1. White AA, Wright SW, Blanco R, et al. Cause-and-effect analysis of risk management files to assess patient care in the emergency department. Acad Emerg Med. 2004; 11:1035–41.
2. Kauchal R, Bates DW, Landrigan C, et al. Medication errors and adverse drug events in pediatric inpatients. JAMA. 2001; 285:2114–20.
3. Glover ML, Sussmane JB. Assessing pediatrics residents' mathematical skills for prescribing medication: a need for improved training. Acad Med. 2002; 77:1007–10.
4. Lammers RL, Byrwa MJ, Fales WD, Hale RA. Simulation-based assessment of paramedic pediatric resuscitation skills. Prehosp Emerg Care. 2009; 13:345–56.
5. Gausche M, Henderson DP, Seidel JS. Vital signs as part of the prehospital assessment of the pediatric patient: a survey of paramedics. Ann Emerg Med. 1990; 19:173–8.
6. Latman NS, Wooley K. Knowledge and skill retention of emergency care attendants, EMT-As, and EMT-Ps. Ann Emerg Med. 1980; 9:183–9.
7. Su E, Schmidt TA, Mann NC, Zechnich AD. A randomized controlled trial to assess decay in acquired knowledge among paramedics completing a pediatric resuscitation course. Acad Emerg Med. 2000; 7:779–86.
8. Youngquist ST, Henderson DP, Gausche-Hill M, Goodrich SM, Poore PD, Lewis RJ. Paramedic self-efficacy and skill retention in pediatric airway management. Acad Emerg Med. 2008; 15:1295–303.

9. Kim J, Neilipovitz D, Cardinal P, Chiu M. A comparison of global rating scale and checklist scores in the validation of an evaluation tool to assess performance in the resuscitation of critically ill patients during simulated emergencies. Sim Healthc. 2009; 4:6–16.
10. Tong A, Sainsbury P, Craig J. Consolidated criteria for reporting qualitative research (COREQ): a 32-item checklist for interviews and focus groups. Int J Qual Health Care. 2007; 19:349–57.
11. Elliott R, Fischer CT, Rennie DL. Evolving guidelines for publication of qualitative research studies in psychology and related fields. Br J Clin Psychol. 1999; 38(Pt 3):215–29.
12. Marshall MN. Sampling for qualitative research. Fam Pract. 1996; 13:522–5.
13. Wears RL. Beyond error. Acad Emerg Med. 2000; 7:1175–6.
14. Croskerry P, Wears RL, Binder LS. Setting the educational agenda and curriculum for error prevention in emergency medicine. Acad Emerg Med. 2000; 7:1194–200.
15. Croskerry P. The cognitive imperative: thinking about how we think. Acad Emerg Med. 2000; 7:1223–31.
16. Handler JA, Gillam M, Sanders AB, Klasco R. Defining, identifying, and measuring error in emergency medicine. Acad Emerg Med. 2000; 7:1183–8.
17. Clarke JR, Spejewski B, Gertner AS, et al. An objective analysis of process errors in trauma resuscitations. Acad Emerg Med. 2000; 7:1303–10.
18. Graber M, Gordon R, Franklin N. Reducing diagnostic errors in medicine: what's the goal? Acad Med. 2002; 77:981–92.
19. Croskerry P. Achieving quality in clinical decision making: cognitive strategies and detection of bias. Acad Emerg Med. 2002; 9:1184–204.
20. Croskerry P. The importance of cognitive errors in diagnosis and strategies to minimize them. Acad Med. 2003; 78:775–80.
21. Hobgood C, Croskerry P, Wears RL, Hevia A. Patient safety in emergency medicine. In: Tintinalli JE, Kelen GD, Stapczynski JS (Eds). Emergency Medicine: A Comprehensive Study Guide. 6th ed. New York, NY: McGraw-Hill, 2003, pp 1912–8.
22. Robinson-Riegler G, Robinson-Riegler B. Cognitive Psychology. Boston, MA: Pearson A & B, 2004.
23. Bond WF, Deitrick LM, Eberhardt M, et al. Cognitive vs. technical debriefing after simulation training. Acad Emerg Med. 2006; 13:276–83.
24. Campbell SG, Croskerry P, Bond WF. Profiles in patient safety: a ''perfect storm'' in the emergency department. Acad Emerg Med. 2007; 14:743–9.
25. Cannon-Bowers JA, Salas E. Individual and team decision making under stress: theoretical underpinnings. In: Cannon-Bowers JA, Salas E (Eds). Decision Making Under Stress: Implications for Individual and Team Training. Washington, DC: American Psychological Association, 2008, pp 17–38.
26. Johnston JH, Poirier J, Smith-Jentsch KA. Decision making under stress: creating a research methodology. In: Cannon-Bowers JA, Salas E (Eds). Decision Making Under Stress: Implications for Individual and Team Training. Washington, DC: American Psychological Association, 2008, pp 39–59.
27. Brown K. EMSC Partnership for Children/National Association of EMS Physicians model pediatric protocols: 2003 Revision. Prehosp Emerg Care. 2004; 8:343–65.
28. American Heart Association. 2005 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care: Part 12: Pediatric Advanced Life Support. Circulation. 2005; 112:IV167–87.
29. Norcini J. Setting standards on educational tests. Med Educ. 2003; 37:464–9.
30. Taylor-Adams S, Vincent C. Systems Analysis of Clinical Incidents: The London Protocol. Available at: http://www1.ic.ac.uk/resources/DA2A75EF-AA84-4E1C-8A1F-DD63808058E7/the_london_protocol.pdf. Accessed Oct 17, 2011.
31. United States Department of Veterans Affairs. National Center for Patient Safety: Cognitive Aids. Available at: http://www.patientsafety.gov/CogAids/RCA/index.html#page=page-1. Accessed Oct 31, 2011.
32. Latino RJ. Patient Safety: The PROACT Root Cause Analysis Approach. Hopewell, VA: CRC Press, 2009.
33. Kohn LT, Corrigan JM, Donaldson MS (Eds). To Err is Human: Building a Safer Health System. Committee on Quality of Health Care in America. Washington, DC: Institute of Medicine, National Academies Press, 2000.
34. Ishikawa K. Guide to Quality Control. White Plains, NY: Asian Productivity Organization, Krause International Publications, 1982.
35. Eastwood KJ, Boyle MJ, Williams B. Paramedics' ability to perform drug calculations. World J Emerg Med. 2009; 10:240–3.
36. Rosen MA, Salas E, Wilson KA, et al. Measuring team performance in simulation-based training: adopting best practices for healthcare. Sim Healthc. 2008; 3:33–41.
37. Nelson KL, Shilkofski NA, Haggerty JA, Saliski M, Hunt EA. The use of cognitive aids during simulated pediatric cardiopulmonary arrests. Sim Healthc. 2008; 3:138–45.
38. Lammers RL, Davenport M, Korley F, et al. Teaching and assessing procedural skills using simulation: metrics and methodology. Acad Emerg Med. 2008; 15:1079–87.
39. Williams RG, Barrows HS, Verhulst SJ, Colliver JA, Marcy M, Steward D. Direct, standardized assessment of clinical competence. Med Educ. 1987; 21:482–9.

Supporting Information

The following supporting information is available in the online version of this paper:

Data Supplement S1. Performance scoring form: checklist-based protocol.

Data Supplement S2. Simulated environment of the infant's room in the mobile simulation unit.

Data Supplement S3. Simulated environment of the ambulance interior in the mobile simulation unit.

The documents are in PDF format.

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