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Dosing Errors Made by Paramedics During Pediatric Patient Simulations After Implementation of a State-Wide Pediatric Drug Dosing Reference

John D. Hoyle, Jr., MD, Glenn Ekblad, DO, MSN, MPH, Tracy Hover, BS, Alyssa Woodwyk, MS, Richard Brandt, MS, Bill Fales, MD, Richard L. Lammers, MD

Abstract

Background: Drug dosing errors occur at a high rate for prehospital pediatric patients. To reduce errors, Michigan implemented a state-wide pediatric dosing reference (PDR), with doses listed in milliliters, the requirement that doses be drawn into a smaller syringe from a preloaded syringe using a stopcock, and dilution of certain drugs to different concentrations. **Purpose:** To evaluate the rate of medication errors, including errors of omission and commission, after implementation of a state-wide PDR. **Methods:** EMS crews from 15 agencies completed 4 validated, simulation scenarios: an infant seizing, an infant cardiac arrest, an 18-month-old with a burn, and 5-year-old with anaphylactic shock. Agencies were private, public, not-for-profit, for-profit, urban, rural, fire-based, and third service. EMS crews used their regular equipment and were required to carry out all the steps to administer a drug dose. Two evaluators scored crew performance via direct observation and video review. An error was defined as ≥20% difference compared to the weight-appropriate dose. Descriptive statistics were utilized. **Results:** A total of 142 simulations were completed. The majority of crews were (58.3%) Emergency Medical Technician-Paramedic (EMTP)/EMTP. For the cardiac arrest scenario, 51/70 (72.9%; 95% CI: 60.9%, 82.8%) epinephrine doses were correct. There were 6 (8.6%, 95% CI: 2.0%, 15.1%) 10-fold overdoses and one (1.4%; 95% CI: –1.4%, 4.2%), 10-fold under dose. In the seizure scenario, 28/50 (56.0%; 95% CI: 42.2%, 69.8%) benzodiazepine doses were correct; 6/18 (33.3%; 95% CI: 11.5%, 55.1%) drug dilutions were incorrect resulting in dosing errors. Unrecognized air was frequently entrained into the administration syringe resulting in under doses. Overall, 31.2% (95% CI: 25.5%, 36.6%) of drug doses were incorrect. Obtaining an incorrect weight led to a drug dosing error in 18/142 (12.7%, 95% CI: 7.2%, 18.2%) cases. Errors of omission included failure to check blood sugar in the seizure scenario and failure to administer epinephrine and a fluid bolus in anaphylactic shock. **Conclusion:** Despite implementation of a PDR, dosing errors, including 10-fold errors, still occur at a high rate. Errors occur with dilution and length-based tape use. Further error reduction strategies, beyond a PDR and that target errors of omission, are needed for pediatric prehospital drug administration. **Key words:** pediatric; drug dosing; patient safety; medication errors; adverse drug events

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In accordance with Taylor & Francis policy and our ethical obligation as researchers, we are reporting that J.D. Hoyle holds the U.S. patents on 2 drug-dosing devices. He currently has no licensing or royalty arrangements for these patents and receives no income from them. He has an approved plan for managing any potential conflicts arising from these patents. The remaining authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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Address correspondence to John D. Hoyle, Jr., Department of Emergency Medicine, Department of Emergency Medicine and Pediatrics and Adolescent Medicine, Western Michigan University, Homer Stryker, MD School of Medicine, 1000 Oakland Dr., Kalamazoo, MI 49008, USA. E-mail: john.hoyle@med.wmich.edu

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Introduction

Multiple studies have demonstrated that pediatric prehospital drug-dosing errors occur at a high rate (1–9). These studies have revealed an error rate

10-11 kilograms *(21-25 pounds)* /11-18 Months (Purple)

CONDITIONS/MEDICATIONS

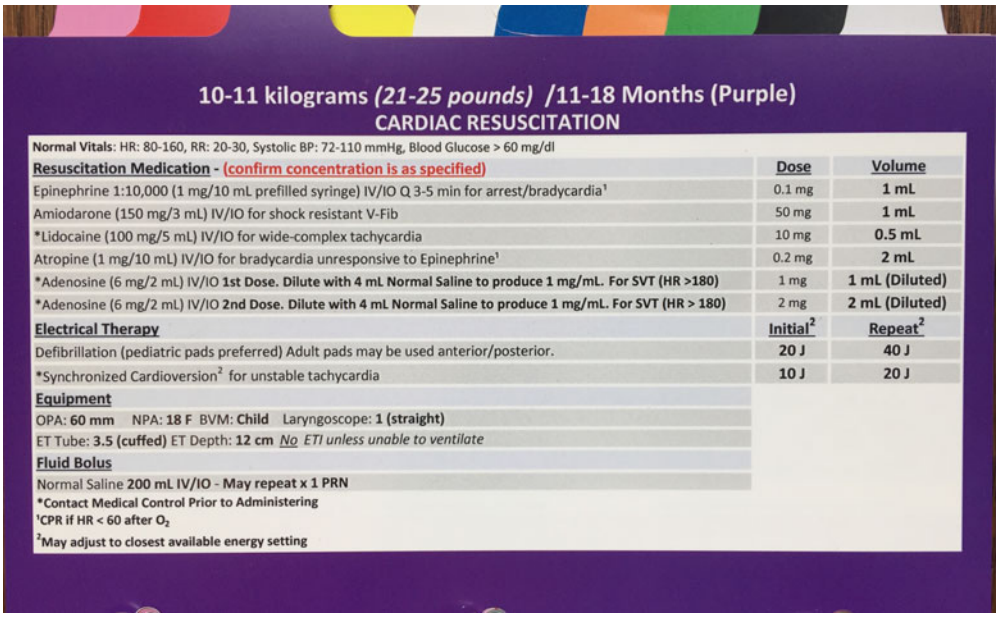
Normal Vitals: HR: 80-160, RR: 20-30, Systolic BP: 72-110 mmHg, Blood Glucose > 60 mg/dl

Development: (12 mos) Able to cruise and beginning to walk. (15-18 mos) Uses cup well along with some spoon agility.

Condition	Medication - (confirm concentration is as specified)	Dose	Volume
Bronchospasm Anaphylaxis	Albuterol Nebulized (2.5 mg/3 mL)	2.5 mg	3 mL
	Ipratropium Bromide Nebulized (0.5 mg/2.5 mL if wheezing)	0.25 mg	1.25 mL
	Diphenhydramine IM/IV/IO (50 mg/mL) **Diluted with 4 mL Normal Saline = 10 mg/mL (Anaphylaxis only)**	10 mg	1 mL (Diluted)
	Epinephrine 1:1000 IM (1 mg/mL) *or* 1 EpiPen Jr. IM **(Severe symptoms only)**	0.1 mg	0.1 mL IM
	Solu-Medrol IV/IO (125 mg/2 mL) **Diluted with 3 mL Normal Saline = 25 mg/mL**	20 mg	0.8 mL (Diluted)
Seizure	Midazolam IM (5 mg/mL) **Give first if no IV**	1 mg	0.2 mL IM
	Midazolam IV (5 mg/mL) **Diluted with 4 mL Normal Saline = 1 mg/mL**	0.5 mg	0.5 mL (Diluted)
Fever	Acetaminophen PO (160 mg/5 mL)	120 mg	3.75 mL PO
Hypoglycemia (<60 mg/dL)	D25% (12.5 g/50 mL) **25 mL of D50% diluted with 25 mL of Normal Saline = D25% Give Slow IV**	5.0 g	20 mL (D25%)
	Glucagon IM (1 mg/mL)	0.5 mg	0.5 mL IM
Pain Control	Fentanyl IV (100 mcg/2 mL) **Diluted with 8 mL Normal Saline = 10 mcg/mL**	10 mcg	1 mL (Diluted)
	Fentanyl IN (100 mcg/2 mL) **Divide dose equally between both nostrils**	10 mcg	0.2 mL IN
	Morphine IV/IM/IO (10 mg/mL) **Diluted with 9 mL Normal Saline = 1 mg/mL**	1 mg	1 mL (Diluted)
Narcotic OD	Naloxone IV/IM (2 mg/2 mL)	1 mg	1 mL
	Naloxone IN (2 mg/ 2mL) **Divide dose equally between both nostrils**	1 mg	1 mL IN
Fluid Bolus	Normal Saline **200 mL IV/IO - May repeat x 1 PRN**	N/A	200 mL
Equipment	OPA: **60 mm** NPA: **18 F** BVM: **Child** Laryngoscope: **1 (straight)** ET Tube: **3.5 (cuffed)** ET Depth: **12 cm** *No ETI unless unable to ventilate*		

3-5 kilograms 6-12 pounds | 7 kilograms 13-16 pounds | 9 kilograms 17-20 pounds | 10-11 kilograms 21-25 pounds | 12-14 kilograms 26-31 pounds | 16-18 kilograms 32-40 pounds | 19-23 kilograms 41-51 pounds | 24-29 kilograms 52-64 pounds | 30-36 kilograms 65-79 pounds | Adult >14 Years

FIGURE 1. Pediatric Drug Reference for 10–11 kg patient.



10-11 kilograms *(21-25 pounds)* /11-18 Months (Purple)

CARDIAC RESUSCITATION

Normal Vitals: HR: 80-160, RR: 20-30, Systolic BP: 72-110 mmHg, Blood Glucose > 60 mg/dl

Resuscitation Medication - (confirm concentration is as specified)	Dose	Volume
Epinephrine 1:10,000 (1 mg/10 mL prefilled syringe) IV/IO Q 3-5 min for arrest/bradycardia[1]	0.1 mg	1 mL
Amiodarone (150 mg/3 mL) IV/IO for shock resistant V-Fib	50 mg	1 mL
*Lidocaine (100 mg/5 mL) IV/IO for wide-complex tachycardia	10 mg	0.5 mL
Atropine (1 mg/10 mL) IV/IO for bradycardia unresponsive to Epinephrine[1]	0.2 mg	2 mL
*Adenosine (6 mg/2 mL) IV/IO **1st Dose. Dilute with 4 mL Normal Saline to produce 1 mg/mL. For SVT (HR >180)**	1 mg	1 mL (Diluted)
*Adenosine (6 mg/2 mL) IV/IO **2nd Dose. Dilute with 4 mL Normal Saline to produce 1 mg/mL. For SVT (HR > 180)**	2 mg	2 mL (Diluted)
Electrical Therapy	**Initial[2]**	**Repeat[2]**
Defibrillation (pediatric pads preferred) Adult pads may be used anterior/posterior.	20 J	40 J
*Synchronized Cardioversion[2] for unstable tachycardia	10 J	20 J
Equipment		
OPA: **60 mm** NPA: **18 F** BVM: **Child** Laryngoscope: **1 (straight)**		
ET Tube: **3.5 (cuffed)** ET Depth: **12 cm** *No ETI unless unable to ventilate*		
Fluid Bolus		
Normal Saline **200 mL IV/IO - May repeat x 1 PRN**		

***Contact Medical Control Prior to Administering**

[1]**CPR if HR < 60 after O_2**

[2]**May adjust to closest available energy setting**

FIGURE 2. Pediatric Drug Reference for 10–11 kg patient.

>30% for all drugs with an error rate for epinephrine of >60% (1, 4, 7–9). In a national survey of paramedics, 42.8% stated they were familiar with a case where a pediatric patient had received an incorrect dose of medication (3). Review of pediatric emergency medical services (EMS) cases has shown that administering a medication increases the odds of a severe patient safety event (10). Based on prior research, prehospital drug dosing errors affect approximately 22,000 children under 12 years old in the United States each year (1). Drug dosing errors in the hospital setting have been shown to cause morbidity and mortality (11, 12).

Prior research has shown that one contributing cause to pediatric prehospital drug dosing errors is paramedics performing drug dose calculations (2, 5, 13). Such calculations can be a complicated multi-step process that requires obtaining an accurate patient weight, recall of the correct dose of drug per kilogram, correct multiplication of weight times dose, conversion of dose in milligrams or grams to milliliters, drawing up the correct number of milliliters,

and administering the correct number of milliliters to the patient. An error at any one of these steps can lead to a dosing error. Carrying out such calculations represent a significant cognitive load on paramedics who often have limited real-life experience or recent training on pediatric drug dosing (1). In addition, paramedics frequently must carry out such tasks in chaotic and austere environments without the ancillary support, such as additional personnel or pharmacists, found in the hospital (1).

In order to decrease pediatric prehospital drug dosing errors, the state of Michigan adopted the MI-MEDIC Emergency Medical Services pediatric dosing reference (PDR) in 2014 with the goal of eliminating drug calculations (Figures 1 and 2) (14). The PDR is required for use by all Michigan EMS agencies and is consistent with Michigan's statewide Pediatric EMS Protocols and the National EMS Model Clinical Guidelines (15). The PDR includes the patient condition (e.g., bronchospasm/anaphylaxis, seizure, hypoglycemia, cardiac resuscitation), drug, dose in milligrams, and dose volume in milliliters. It is color-coded to correlate with the Broselow–Luten Tape (BLT). Prior to introduction of the PDR, paramedics typically relied on memory for drug doses and had to carry out mathematical calculations for all doses. Prior to introduction of the PDR, there was no standard reference mandated by state protocol.

The PDR requires dilution of certain drugs to more standard concentrations with instructions on how to complete dilutions. For pediatric patients (those <37 kg) adenosine, diphenhydramine, methylprednisolone, midazolam (for IV administration), dextrose, and fentanyl (for IV administration) require dilution. For adults, only midazolam and fentanyl for IV administration require dilution. As an example, midazolam is supplied in a 5 mg/1 mL concentration. For IV administration, the PDR provides instructions to dilute the 1 ml of midazolam with 4 ml of saline to produce a 1 mg/1 mL concentration. This process is carried out by using a 10-mL saline flush syringe, pushing out 6 mL of saline and drawing up the one mL of drug. Then, a 3-way stopcock is attached to the 10-mL syringe containing the diluted drug and a 1-mL or 3-mL syringe is attached to the stopcock. The diluted drug is then transferred into the smaller administration syringe. When the PDR was introduced, it was accompanied by an on-line training program as well as instruction on drug dilution and administration. The Michigan Division of EMS and Trauma, which is the state EMS licensing agency, requires Emergency Medical Technician-Paramedics (EMTPs) in Michigan to complete an on-line pediatric medication administration course bi-annually. This course covers use of the PDR, drug dilution, and drug administration.

We sought to determine the impact of the PDR on drug dosing errors utilizing 4 pediatric simulation scenarios with EMS crews from 15 different EMS agencies throughout Michigan and compare errors found in simulation before and after implementation of the PDR. We further sought to identify errors of omission and commission in these scenarios.

Methods

Study Population and Design

This study was approved by the Michigan Department of Health and Human Services Institutional Review Board. This study is covered under a Michigan Department of Health and Human Services special project designation similar to a federal certificate of confidentiality.

This was an observational study of paramedics in a convenience sample of 15 EMS agencies throughout Michigan. This study is a subanalysis of an on-going quality improvement study, the Michigan Pediatric EMS Error Reduction Study (MI-PEERS). The agencies were public, private, not-for-profit, for-profit, third-service and fire-based. These agencies represented urban, suburban and rural service populations. The combined service population of the agencies was approximately 2.5 million persons or 24.7% of the state's population based on 2018 U.S. Census data (16). In order to be included in the simulations for the study, crew members had to be licensed providers for a study agency. Crews configurations represented the typical crew configurations for each agency.

Each crew completed 4 previously validated pediatric simulation scenarios; (1) an infant with a seizure who was also hypoglycemic, (2) an 18-month-old with a partial thickness burn, (3) a 5-year-old with anaphylactic shock, and (4) an infant in cardiac arrest (4, 7, 8). Manikins utilized were Newborn Hal (infant), Pediatric HAL (18-month-old), and HAL Jr (5-year-old) (Gaumard, Miami, FL). Each of the crews completed all 4 of the scenarios in the same order in one discrete time period. Crews were required to use their usual equipment and drug bags. If an agency's medical control did not allow for their drugs to be used, the study team provided them with sham drugs that were identical to their usual drugs. Crews were required to carry out all of the usual steps to administer drugs to a patient, including determining the simulated patient's weight, calculating the dose, drawing the drug up, diluting if required and injecting the drug. For EMTP/EMTP crews, the crew made the determination as to who would determine,

draw up and administer drug doses. Drug administration is not in the scope of practice for Emergency Medical Technician-Basics (EMTBs) and Emergency Medical Technician-Intermediates (EMTIs). In the EMTP/EMTB and EMTP/EMTI crews, the EMTP determined, drew up, and administered drug doses. If the EMS crew asked, they could obtain a correct weight, in pounds, from the simulated patient's guardian in 2 of the cases (the infant cardiac arrest and the 18-month-old burn). In the remaining cases (the infant seizing and the 5-year-old with anaphylactic shock), the guardian did not know a weight, and the crew would have to obtain a weight from some other method (BLT, simulated patient age, etc.) A dose error was defined as ≥20% difference from the weight-appropriate dose based on definitions used in prior research (1, 9).

Data Collection and Analysis

Simulations took place in a either a mobile simulation unit or simulation center. Simulation sessions were recorded using professional-grade security video cameras with digital zoom capability and video software. Two study team members (JH, GE) directly observed all simulations in the simulation space and graded performance on a standardized scoring sheet. Each simulation session video was reviewed by the study staff (JH, GE, TH) and scoring was discussed. Any disagreements regarding a scoring item were resolved by consensus. If consensus could not be reached, the item was scored as correct.

Data from the scoring sheet was entered into RedCap (Research Electronic Data Capture) (17). Data was exported into Excel (Microsoft, Redmond, OR) and analyzed using SAS software (SAS, Cary, NC, V 9.4) to produce descriptive statistics with means, medians and confidence intervals. Drug dosing errors for the current study were compared to results from a simulation study that took place prior to implementation of the PDR (4) for drugs that were analyzed in both studies (epinephrine 1 mg/1 mL, epinephrine 1 mg/10 mL, dextrose, and benzodiazepines).

RESULTS

A total of 142 simulations were completed; Seizure (36), Burn (35), Anaphylactic Shock (36), and Cardiac Arrest (35). Crew demographics are shown in Table 1. The dose error rate for specific drugs is shown in Table 2. Overall 31.2% of drug doses were incorrect. Overdoses are shown in Table 3 and under doses are shown in Table 4. Errors made when drugs were diluted are shown in Table 5. In the seizure scenario,28/50 (56.0%; 95% CI: 42.2%, 69.8%) benzodiazepine doses were correct; 6/18 (33.3%; 95% CI: 11.5%, 55.1%) drug dilutions were incorrect resulting in dosing errors. In 1/36 seizure cases (2.8%; 95% CI: –2.6%, 8.2%) the crew was unable to dilute D50 to D25 despite using the PDR and reading the dilution instructions. They abandoned their attempt and administered glucagon. Table 6 demonstrates errors for specific drugs, assessed via simulation, before and after implementation of the PDR.

TABLE 1. Crew demographics

Parameter	Number/%
Sex	Male 44/65 (67.7%)
Years of experience	
<1 year	11 (16.92%)
1–2 years	11 (16.92%)
3–4 years	8 (12.31%)
5–7 years	14 (21.54%)
8–10 years	10 (15.38%)
11–15 years	6 (9.23%)
16–20 years	5 (7.69%)
Crew configuration	
EMTP/EMTP	21 (58.3%)
EMTP/EMTB	12 (33.3%)
EMTP/EMTI	3 (8.3%)

EMTP = Emergency Medical Technician-Paramedic; EMTB = Emergency Medical Technician-Basic; EMTI = Emergency Medical Technician-Intermediate.

Six (8.6%, 95% CI: 2.0%, 15.1%) of the 1 mg/10 mL epinephrine doses for cardiac arrest were 10-fold overdoses. There was one (1.4%, 95% CI: –1.4%, 4.2%) 10-fold under dose. The under dose occurred when a 2-paramedic crew stated that "we dilute all drugs for peds" and diluted the cardiac epinephrine, which is not diluted per the PDR. Unrecognized air bubbles were in the administration syringe in 31/264 (11.7%, 95% CI: 8.1%, 16.3%). These were administered to the simulated patient and contributed to under dosing. This included one case where the entire 1-mL dose was air. Analysis of this error revealed the following: the EMTP had the stopcock turned off to the 1-mL syringe they were trying to fill from the 10-mL syringe containing diluted fentanyl. The 1-mL administration syringe was placed into the stopcock port but was not seated tightly. This allowed air to be drawn into the administration syringe from around the stopcock hub when the EMTP thought they had filled the syringe with liquid from the 10 mL containing diluted fentanyl through the stopcock. We compared the drug dose error rate in simulations before the PDR was introduced (4) to the error rate after the PDR was introduced for drugs that were used in both time periods (Table 6). The error rate has significantly decreased following the PDR introduction.

Errors of omission were found in the seizure, anaphylactic shock and burn simulation scenarios. In the seizure scenario, failure to check a blood glucose occurred in 7/36 (19.4%, 95% CI: 8.2%, 36.0%) cases. In the anaphylactic shock case, epinephrine was not

Table 2. Total number of doses and number correct

Drug/route	# Correct/total	% Correct (95% CI)
Midazolam IM	21/32	65.6% (46.8%, 81.4%)
Midazolam IV	7/18	38.9% (17.3%, 64.3%)
Dextrose	20/28	71.4% (51.3%, 86.9%)
Epinephrine (1 mg/1 mL) IM	22/30	73.3% (54.1%, 87.7%)
Diphenhydramine	24/30	82.8% (64.2%, 94.2%)
Methylprednisolone	10/13	76.9% (46.2%, 95.0%)
Fentanyl IN	2/4	50.0% (6.8%, 93.2%)
Fentanyl IV	37/57	64.9% (51.1%, 77.1%)
Morphine IV	4/6	66.7% (22.3%, 95.7%)
Epinephrine (1 mg/10 mL or 1:10,000) IV	51/70	72.9% (60.9%, 82.8%)
All drugs	198/288	68.8% (63.5%,74.2%)

Table 3. Overdoses

Drug/route	Number of overdoses	Magnitude of overdose (median and range)	95% Confidence Interval of median
Midazolam IM	2	2.25 (0.50)	(2.00, 2.50)
Midazolam IV	8	3.75 (3.50)	(2.00, 5.00)
Dextrose	3	7.69 (6.15)	(1.54, 7.69)
Epinephrine (1 mg/1 mL) IM	4	6.67(2.00)	(4.67, 6.67)
Fentanyl IN	1	1.25*	*
Fentanyl IV	16	5.00 (10.75)	(2.40, 8.00)
Morphine IV	2	6.10(8.20)	(2.00, 10.20)
Epinephrine (1 mg/10 mL or 1:10,00) IV	13	3.6 (18.60)	(1.60, 10.00)

*Confidence intervals could not be calculated for a single incidence.

Table 4. Under doses

Drug/route	Number of under doses	Magnitude of under dose(median and range)	95% Confidence Interval of median
Midazolam IM	9	0.50 (0.70)	(0.10, 0.60)
Midazolam IV	3	0.75 (0.15)	(0.60, 0.75)
Dextrose	5	0.73 (0.49)	(0.28, 0.77)
Epinephrine (1 mg/1 mL) IM	4	0.67 (0)	(0.67, 0.67)
Diphenhydramine	2	0.55 (0.10)	(0.50, 0.60)
Methylprednisolone	1	0.43 (0)	*
Fentanyl IN	1	0.25 (0)	*
Fentanyl IV	4	0.60 (0.70)	(0.00, 0.70)
Morphine IV	0	N/A	N/A
Epinephrine (1 mg/10 mL or 1:10,00) IV	6	0.07 (0.70)	(0.01, 0.70)

*Confidence intervals could not be calculated for a single incidence.

Table 5. Dilution errors

Drug/route	Dilution errors #/(% of total doses)	Overdoses/Under doses#/#
Midazolam IM	3 (11.1%)	0/3
Midazolam IV	6 (41.7%)	3/3
Dextrose	6 (27.3%)	2/3
Epinephrine (1 mg/1 mL) IM	0	0/0
Diphenhydramine	4 (6.9%)	2/2
Methylprednisolone	0	0/0
Fentanyl IN	1 (33. 3%)	0/1
Fentanyl IV	9 (6.8%)	7/0
Morphine IV	1 (16.7%)	0/0
Epinephrine (1 mg/10 mL or 1:10,00) IV	1 (1.5%)	0/1

TABLE 6. Dose errors pre and post MI-MEDIC pediatric drug reference implementation

Drug (Indication)	Percent of correct doses (95% Confidence Interval) pre PDR	Percent of correct doses (95% Confidence Interval) post PDR
Midazolam (seizure)	24.0%*†	65.6% (46.8%, 81.4%)‡
Dextrose (seizure)	6% (2.5%, 8.8%)	71.4% (51.3%, 86.9%)
Epinephrine 1 mg/mL IM (anaphylaxis)	25.0% (9.7%, 30.3%)	73.3 % (54.1%, 87.7%)
Epinephrine 1 mg/10 mL IV (cardiac arrest)	31.0%*	72.9% (60.9%, 82.8%)

*Confidence interval not given in comparison publication.
†Comparison study allowed for administration of "any benzodiazepine."
‡Data represent first dose of midazolam administered intramuscularly.

administered in 6/36 (16.7%, 95% CI: 6.4%, 32.8%), a fluid bolus was not administered in 14/36 (38.9%, 95% CI: 23.1%, 56.5%), diphenhydramine was not administered in 4/36 (11.1%, 95% CI: 0.8%, 21.4%), and methylprednisolone was not administered in 8/36 (22.2%, 95% CI: 8.6–35.8). For the burn case, in 1/35 (2.9%, 95% CI: 0.0%, 14.9%) cases, no initial pain medicine was administered and in 5/35 (14.3%, 95% CI: 4.8%, 30.3%) cases, a second dose of pain medicine was not administered, despite a high pain score.

Errors of commission included administration of atropine in 5/35 (14.3%, 95% CI: 2.7%, 25.9%) of the cardiac arrest cases. Two simulated patients (5.7%, 95% CI: –2.0%, 13.4%) were intubated contrary to a restriction on pediatric intubation in state protocols to cases that could not be oxygenated or ventilated with a bag-valve mask. In the seizure scenario, a second dose of midazolam was administered in 9/36 cases (25%, 95% CI: 10.9%, 39.1%) prior to checking a blood glucose and in one case a third dose was administered prior to checking a blood sugar.

The weight used for drug calculation was obtained by using the BLT in 87/142 (61.3%, 95% CI: 52.7%, 69.3%), asking the guardian the child's age in 35/142 (24.7%, 95% CI: 17.8%, 32.6%), asking the guardian how much the child weighed in 17/142 (12.0%, 95% CI: 6.7%, 17.3%), guessing the weight 2/142 (1.4%, 95% CI: 0.2%, 0.5%), and there was no weight estimation in 1/142 (0.0%, 95% CI: 0.0, 0.0). EMS crews asked the guardian how much the child weighed in 55/142 cases (38.7%, 95% CI: 30.7%, 47.3%); however, the weight from the guardian was used for drug calculations in only 17/142 (12%, 95% CI: 6.7%, 17.3%) cases. In these 17 cases, the crew did not use an alternative method (BLT, patient age) to determine the weight for drug calculations and their only source for weight was that given by the guardian. Obtaining an incorrect weight led to a drug dosing error in 18/142 (12.7%, 95% CI: 7.2%, 18.2%) cases.

DISCUSSION

Since the introduction of the MI-MEDIC pediatric drug reference and its associated training, dosing errors, as evaluated by simulation, have decreased. However, dosing errors continue at an unacceptably high rate with 31% of all doses being incorrect. This represents an incremental improvement in patient safety, but leaves significant room for continued improvement. Our results are similar to the results found by Kaji et al. (9), who introduced a quality improvement initiative in 2 counties in California to reduce epinephrine dosing errors. Effectiveness was assessed via chart review. Their effort included a PDR, with doses listed in milligrams instead of milliliters (thus requiring a mathematical calculation) encouragement to use the BLT and the requirement that medical control be contacted after the first dose of epinephrine was administered (9). They found an increase in correct epinephrine doses from 44.2 to 64.9%.

Our study found a similar increase for all of the 7 drugs tested, with multiple routes of administration. From the Kaji et al. study (9) and the current study, one can conclude that a pediatric dosing reference for EMS can reduce errors significantly, but does not eliminate the errors, leaving 31% of doses incorrect (Table 2). We can compare our epinephrine dose error rate to that of Kaji et al (9). We experienced an 8% greater improvement over Kaji et al. (9). The MI-MEDIC PDR has doses listed in milliliters, eliminating mathematical conversions from milligrams to milliliters. The California study reference still required conversion from milligrams to milliliters. Although training differences may have played a role, this suggests that eliminating mathematical conversions and reliance on memorization of pediatric drug doses can have a positive effect on drug dosing accuracy. However, this study also suggests that additional patient safety tools must be tested, in conjunction with the PDR to determine if further error reductions are possible.

One of the strengths of our study was the use of simulation to assess errors. This allowed for expert personnel to observe the entire drug administration process across multiple agencies using standardized cases. Direct observation has been found to identify more adverse drug events versus chart review or incident reporting (18). In fact, many of the errors we found went unrecognized by the personnel that

made them. Since such errors were not realized, it is unlikely they would be documented.

The PDR calls for dilution to make drug concentrations easier to interpret (e.g. making midazolam a 1 mg/1 ml concentration instead of 5 mg/1 ml). The Institute for Safe Medication Practices has stated as one of its safe practice guidelines that "Only dilute IV push medications when recommended by the manufacturer, supported by evidence in peer-reviewed biomedical literature, or in accordance with approved institutional guidelines." They further state that, "Unnecessary dilution adds complexity to the drug administration process and introduces a needless risk of making medication errors and contaminating sterile IV medications or solutions" (19, 20).

Despite written directions on the PDR for dilution, we observed multiple types of errors that lead to under and overdoses. These errors led to over and under-diluted drug solutions and mistaking the diluted volume listed on the PDR for the volume of native drug to be administered followed by a saline flush, which some EMTPs stated they thought was the "dilution." This resulted from misinterpretation of the instructions and lack of familiarity with the dilution process. Dilution is a multistep process that also requires additional equipment (3-way stopcock, flush syringe) beyond what would be used for a drug that is not diluted. This must be found in the equipment bag which adds complexity to the process of delivering a drug dose to a child, already a rare event for an EMTP (1–3).

Since most drugs are not diluted for adults, one of the only times this skill is carried out or practiced is with a pediatric patient. Exceptions to this are fentanyl and midazolam when administered IV, which EMTPs regularly dilute for adult patients. Even with this more frequent skill practice, a decrease in error was not seen compared with other drugs that are not diluted, except when administered to children. A difference in error rate was also seen with midazolam when administered IM (65.6% correct) versus IV (38.9% correct). The PDR requires that IM midazolam be given undiluted while IV midazolam must be diluted. This 26.7% difference in error rate also questions the practice of drug dilution. Although the state of Michigan requires paramedics to complete a pediatric medication administration practical every 2 years, this did not eliminate the errors we observed. One can argue that given the already rare nature of administering a drug to a child (1), and the difficulty EMTPs have with pediatric drug calculations (12, 21), that training every 2 years may not be effective at decreasing errors. A prior Michigan simulation study demonstrated that despite having completed Pediatric Advanced Life Support in the last 6 months, EMTPs had a high rate of pediatric medication dosing errors (5).

Our simulations allowed us to observe a previously undescribed phenomenon for prehospital pediatric medication administration-entrainment of air into the administration syringe and administration of that air to the simulated patient. Although it is doubtful that the amount of air itself would be harmful, it still contributed to under dosing of medication, especially those given in small volume syringes (e.g., 1 mL). This phenomenon was observed when medications were drawn directly into an administration syringe and with transfer to a second syringe for dilution. The training EMS crews receive for dilution requires pushing out a set amount of saline from a pre-loaded 10-mL saline flush syringe, such that the volume matches the dilution volume in the PDR instructions, and then drawing up the entire volume of the supplied drug vial. Next a 3-way stopcock is affixed to the syringe with diluted drug and a smaller administration syringe (e.g., 1 mL or 3 mL) is attached to the stopcock. Diluted drug is then pushed into the administration syringe. An unintended consequence of this process is that the air in the stopcock, typically about 0.2–0.3 mL, is pushed into the administration syringe. In our simulations, this amount of air was rarely recognized or eliminated. A way to avoid this would be to prime the stopcock with diluted drug prior to attaching the administration syringe. Uniformly, this was not done.

We found various errors of omission in our study. Failure to check a blood sugar in the seizing simulated patient occurred 19.4% of cases. This has decreased from 64% in simulation assessment prior to the advent of the PDR. This is a dramatic improvement, but it is uncertain why this improvement occurred. The treatment condition "Hypoglycemia" is located just one condition below the "Seizure" condition on the PDR and it is possible that this served as a visual cue.

There were a number of failures to administer epinephrine and a fluid bolus to the hypotensive anaphylaxis simulated patient. Epinephrine administration and volume expansion are truly lifesaving in anaphylactic shock. The PDR states that epinephrine should be given for "Severe symptoms only". It is possible that this statement unintentionally creates a barrier to epinephrine administration. Another possible explanation is that the drugs are listed in alphabetical order (albuterol, diphenhydramine, epinephrine, solumedrol) on the PDR. It is possible that moving epinephrine to the first position may

increase its rate of administration. For the scenario, the hypotension and tachycardia would not resolve unless epinephrine and a fluid bolus were administered. The PDR lists normal vital signs as well as drug doses. Despite this, there appeared to be failure to recognize hypotension. The quality improvement study that the present study is a part of has placed new emphasis on the appropriate treatment of anaphylaxis including administration of epinephrine, volume expansion for hypotension and recognition of abnormal vital signs. Additional strategies should be employed to improve treatment of anaphylaxis by paramedics. Although there were omissions of pain medicine for the burn simulation, these were relatively low compared to prior studies (22–24). Prior studies examined extremity trauma, while our simulation was a burn. It is possible that pain management is more obvious to a paramedic in a burn, and our simulated patient was crying loudly.

Errors of commission were also common. In the cardiac arrest scenario, atropine was administered in 14.3% of cases and simulated patients were intubated in 5.7% of cases. Neither of these actions is called for by protocol, which calls for epinephrine as the only drug and bag-valve mask for ventilation. Reasons given for the intubations were that the crew was "going to have a long transport" (30 minutes or longer). Given these long transport times, one could argue that intubation is reasonable, although it is not in the protocol. In the seizure scenario, prior to checking the blood glucose, a second and even a third dose of midazolam were administered. In the scenario, the simulated patient was hypoglycemic and the seizure would resolve after administration of one dose of midazolam and one dose dextrose. The Michigan state pediatric protocol calls for administration of midazolam first and then checking blood glucose. In our study, the blood glucose was frequently not checked as rapidly as desired. Strategies to improve this, such as adding a sticker to the midazolam vial that states "check blood sugar" should be investigated.

The EMS crews in our study used multiple methods to obtain the simulated patient's weight. The most frequent method to obtain a weight was the BLT. Crews asked the parent for the weight in 38.7% of the cases, but then utilized this weight (which for purposes of the simulation was considered accurate), in only 12% of the cases suggesting a reluctance to trust the weight from the parent. Two recent systematic reviews have demonstrated that parental estimates are more accurate than the BLT for weight estimation (25, 26). Another study found that emergency medical dispatchers can obtain accurate pediatric weights from 9-1-1 callers (27). Note, however, that weights obtained from parents are in pounds, not kilograms, which adds the potential error of a pounds to kilogram conversion error, or even failure to convert pounds to kilograms at all. A focus group study revealed that paramedics think in pounds, not kilograms, when determining a pediatric patient weight (2), and this may be true with adult patients as well. If paramedics think in terms of pounds and asking the parent for the child's weight is the most accurate method for them, short of a scale weight, then providing a drug dose reference, based on pounds may make sense. The PDR used in this study lists both pounds and kilograms on each page. Further research is needed to see if using weights in pounds instead of kilograms is safer and less error prone.

Significant improvement in drug dosing accuracy has occurred since the introduction of the PDR (14). However, use of the PDR alone has not eliminated errors. These findings are similar to those found by Kaji et al. (9) in their assessment of 1 mg/10 mL epinephrine (9). We were able to demonstrate improved drug dosing accuracy in a benzodiazepine (midazolam), dextrose, and epinephrine 1 mg/1 mL dosing as well. Unlike the PDR used in the Kaji et al. (9) study, the MI-MEDIC PDR has doses listed in milliliters, eliminating the need for math in an emergency situation. With benzodiazepines, it should be noted that the simulation study prior to implementation of the MI-MEDIC PDR called for "any benzodiazepine" to be delivered in order to be scored correctly (4). The EMS protocol at that time called for the benzodiazepine to be delivered via the intravenous or intraosseous route. In contrast, the EMS protocol for the current study calls for the first dose of midazolam to be delivered intramuscularly. It should be noted that if a second dose of midazolam is delivered, the protocol and PDR require that the midazolam be diluted and delivered either intravenous or intraosseous. We noted a decrease in drug dosing accuracy from 65.6 to 38.9% when second doses were given. The act of dilution adds additional steps and equipment, likely adding to cognitive load and contributing to the error rate along with the introduction of air bubbles when utilizing a 3-way stopcock as part of the dilution process.

LIMITATIONS

This study is limited by the fact that these cases were simulations and not real-life events. However, in order to capture this many real-life pediatric cases would require a very large amount of time

and/or funding. Simulation offers advantages over chart or database review in that all aspects of patient care can be monitored and errors identified. It is possible that real-life patient encounters have an increased level of provider stress over simulation leading to increased errors that simulation is unable to capture. This study was conducted with paramedics in one state and may not be generalizable to EMS agencies in other states. However, our study did cover a large number of agencies serving a wide-range of populations and crew configurations. It is possible that the reduction in errors was due to something other than the PDR. However, there was no other significant change made during this time period to account for the difference.

Conclusion

Since the introduction of the MI-MEDIC pediatric dosing reference, medication errors have decreased. However, errors, including 10-fold errors, continue to occur at an unacceptably high rate, with 31% of all doses incorrect. Errors occurred with dilution that resulted in over and under doses of medication. Elimination of dilution, as has been recommended in the hospital setting, should be strongly considered. Unrecognized air bubbles in the administration syringe contribute to under doses. Errors of omission included failure to check blood glucose in seizing simulated patients and failure to administer epinephrine and a fluid bolus in anaphylactic shock. A pediatric dosing reference with the dose volume listed represents an incremental improvement in patient safety. However, in order to eliminate the significant number of remaining errors, additional error reduction strategies, including improved drug dosing systems, more frequent pediatric training and education, regular pediatric drug dosing practice that includes calculating, drawing up and administering drugs, are needed for pediatric prehospital drug administration. Further research is needed to define the safest prehospital pediatric drug administration strategies.

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