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REPORT

Medication Errors in Pediatric Patients after Implementation of a Field Guide with Volume-Based Dosing

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ABSTRACT

Background: Several studies have demonstrated the high frequency of medication errors in pediatric patients by prehospital providers during both patient care and simulation. In 2015, our hospital-based urban EMS system introduced the Handtevy™ Field Guide that provides precalculated pediatric doses in milliliters (mL) by patient age. We hypothesized that implementation of the Field Guide would increase the percentage of correct pediatric medication doses to greater than 85%.

Methods: We performed a single center retrospective cohort study of medications administered to patients $<$ 13 years of age from August 2017 to July 2019 compared to 2014 baseline data through electronic medical record review. We excluded nebulized medications and online medication direction cases. Our primary outcome was the percentage of correct doses defined as a dose within 80–120% of the Field Guide dose recommendation. Each dosing error was reviewed by two investigators.

Results: We analyzed 483 drug administrations in 375 patients for the Field Guide study period. Doses were correct in 89.4% of medication administrations with 68.5% reportedly administered exactly as dictated by the Field Guide compared to 51.1% in the baseline period ($p < 0.001$). During the Field Guide study period, the following medications had 100% appropriate dosing: adenosine, dextrose 10%, diphenhydramine, epinephrine 1:10,000, glucagon, naloxone and oral ondansetron. Overdoses accounted for 4.4% of medication errors and underdoses accounted for 6.2% of medications errors. The most overdosed medications were intranasal (IN) midazolam (11.8%) and intravenous fentanyl (9.4%). The most underdosed medications were IN midazolam (23.5%) and intramuscular epinephrine 1:1000 (12.5%). The highest percentage of errors (20%) were seen in the zero to one-year-old age group.

Conclusion: After implementation of a precalculated mL dose system by patient age for EMS providers, most pediatric medications were reportedly administered within the appropriate dose range. A field guide with precalculated doses (in mL) may be an effective tool for reducing pediatric medication dosing errors by EMS providers.

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Background

Successful resuscitation of a critically ill or injured child requires a systematic approach, a practiced skill set, and accurate medication dosing. A challenge for prehospital providers is they rarely encounter seriously ill or injured children resulting in difficulty maintaining their medical knowledge and skills which may affect their confidence in caring for these children (1). Prehospital providers have fewer support mechanisms for medication administration compared to hospital emergency departments which have computerized order entry, automated drug dispensing, and pharmacists verifying doses. This lack of support in the field leads to greater stress and cognitive load resulting in errors due to incorrect recollection of the appropriate dose and inaccurate dosing calculations (2).

A joint policy statement on equipment for ambulances recommends the use of a length/weight-based tape (LBT) or appropriate reference material for pediatric equipment sizing and drug dosing based on known or estimated weight in optimizing prehospital care delivery. These systems have been shown to reduce dosing errors and improve speed to administration of medications in the prehospital environment (3).

Several studies have illustrated the high frequency of medication errors in pediatric patients by prehospital providers during both patient care and simulation (2, 4–9). Incorrect dose ranges for resuscitation medications include epinephrine 21–72% (4, 6–9), benzodiazepines 44–60% (2, 4), diphenhydramine 54–93% (6, 7) and dextrose 29–64% (4, 7, 8). No study has analyzed EMS medication errors with the use of a field guide in the clinical setting.

Our EMS system introduced the Handtevy™ Field Guide (Pediatric Emergency Standards Inc, Davie, FL) in July 2015. The Field Guide includes an LBT based on age, specific age-

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appropriate vital signs, equipment recommendations by age and a customized preprinted medication guide based on the institution's formulary that gives providers the weigh-based dose along with precalculated medication doses in milliliters (mL) by age. The primary outcome measure of our study was the percentage of correct doses after the introduction of the Field Guide. We hypothesized that implementation of the Field Guide would increase the percentage of correct pediatric medication doses to greater than 85% from baseline. Our secondary outcomes measures were percentage of overdose and underdose medication administration, and percentage of incorrect doses by age.

Methods

Study Design

We performed a single center retrospective cohort study of all medications administered to patients < 13 years of age from July 2017 to June 2019 compared to 2014 baseline data through electronic medical record review. For the Field Guide study period, our primary outcome was the percentage of correct doses defined as administering a dose within 80–120% of the Field Guide dose by age which was consistent with prior literature (7, 10–13). For the baseline period, the correct dose was defined as administering a dose within 80–120% of the calculated correct dose based on the recorded weight. This study was approved by the Colorado Multiple Institutions Review Board (COMIRB # 19-0611).

Setting

Our hospital-based urban EMS system is a single-tier all Advanced Life Support, with Basic Life Response first response. Our system is the sole provider of 9-1-1 services to the city and surrounding county which is 154.7 square miles with an approximate population of 700,000 in 2018 with a growth rate of 1.5% per year. We employ 215 paramedics and respond to more than 118,000 calls annually. All paramedics have been trained in either Pediatric Advanced Life Support or Pediatric Education for Prehospital Professionals.

Outcome Measures

We queried our EMS electronic health reporting software, ESO© (ESO Product Ecosystem, Austin, TX) for all medication administrations to patients < 13 years of age from August 2017 to July 2019, which was two years after the introduction of the Field Guide system on our ambulances in July of 2015. Data were exported using ESO's built-in ad hoc reporting system, Logi10 Ad Hoc Reporting©(ESO Product Ecosystem, Austin, TX), into Excel™ (Microsoft Corporation, Redmond, WA). For 2014 baseline data, we queried our previous EMS electronic health reporting software, High Plains RMS (High Plains Information Systems, Centennial, CO) for medications administered to patients < 13 years of age. We then reviewed each ePCR (electronic patient care reporting) for medication names, doses, and routes after the ePCR was imported into ESO©. For the study period, one investigator (GM) reviewed all EMS records retrospectively to assess for dosing errors and ensure consistency in documentation between the medication administration section and narrative. Any medication errors or incorrect documentation were reviewed by a second investigator (LR). In cases of inconsistency, the narrative information was used over other documentation sections such as drop-down menus and checkboxes, as these tend to be prone to more errors than free text entry (14). For the baseline period, one investigator (LR) reviewed all charts from January through July 2014, and a second investigator (GM) reviewed all charts from June through December 2014. There was 100% concordance between the two investigators for June 2014. All doses were documented in milligrams (mg) in the ePCR. Correct doses using the Field Guide system can be determined by age or by using a LBT. Appropriate doses could be based on patient's stated age by either the patient or a family member, or rounded age (i.e. if a patient or family member says, "almost ten years old," paramedics could either use nine or ten years to select the appropriate dose). Paramedics first asked the parent or caretaker for age. The LBT was only used if no one at the scene could provide the age. When the LBT was used, appropriate dose was determined based on the LBT. During the baseline period, paramedics asked the parents or caretaker for the weight of the child, used the Broselow™ LBT or estimated the weight of the child based on size. Paramedics had access to online protocols during the baseline period which provided dosing recommendations for medications in mg/kg (milligrams/kilogram). Reviewers were not blinded to the primary outcome of the study.

Inclusion/Exclusion Criteria

Prehospital medication administration to patients < 13 years of age were included. We excluded nebulized medications. We also excluded cases when paramedics called for medical direction to the base physician prior to administering medications as well as cases when medication indication fell outside of the Field Guide protocols.

Analyses

Continuous variables were presented as medians with interquartile ranges (IQR) as their distributions were not normal. Nominal variables were presented as percentages. Continuous variables were analyzed with a Mann Whitney U test due to their non-normal distributions. Nominal variables were analyzed with either a Chi Square test or Fisher's exact test. A relative risk with 95% CI (confidence intervals) was calculated. Statistical analyses including graphs were performed with Excel™ (Microsoft Corporation, Redmond, WA) and R© version 3.6.2 (The R Foundation, Vienna, Austria).

Results

During the Field Guide study period, there were 7,591 patient encounters with children < 13 years of age. Our

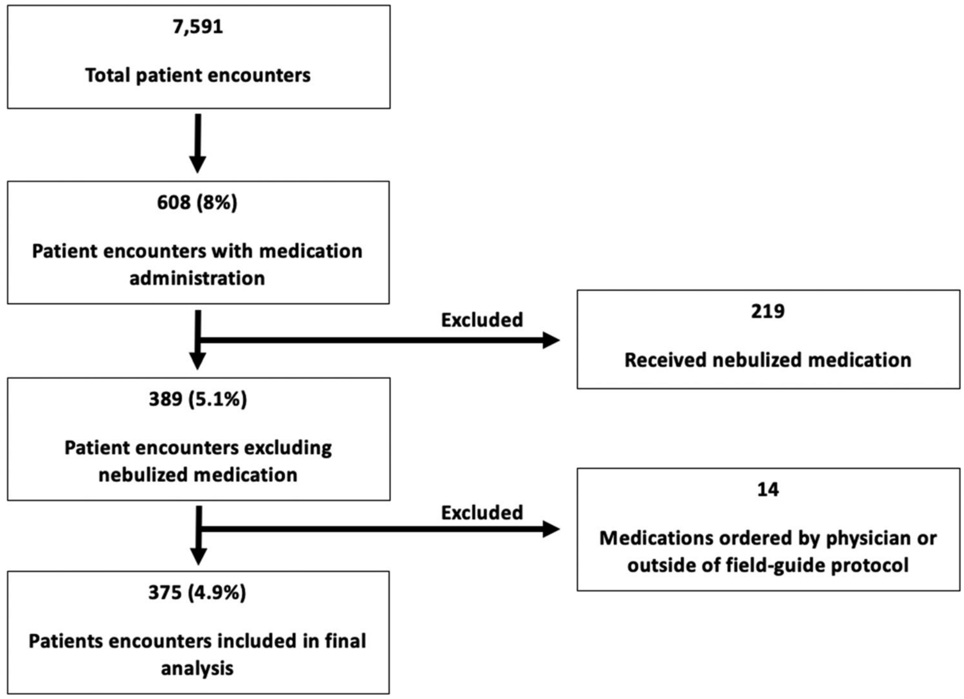

Figure 1. Patient encounters < 13 years of age from August 2017 to July 2019.

initial query returned 608 (8%) patient encounters with medication administration. After exclusion of 219 encounters with nebulized medications and 14 encounters with medications ordered by a physician or outside the Field Guide protocols, 483 medication administered during 375 (4.9%) patient encounters were analyzed (Figure 1). For the baseline period during 2014, there were 274 medications administered during 206 patient encounters. Age and gender were similar between the two time periods. Race and ethnicity were not consistently documented in the ePCR in 2014 (Table 1).

Doses were correct in 89.4% (432/483) of medication administrations with 68.5% (331/483) of doses reportedly administered exactly as dictated by the Field Guide during the study period as compared to 51.1% (140/274) in the baseline period ($p < 0.0001$). Patients in the Field Guild study period were 1.8 times (95% CI 1.6, 2.0) more likely to receive the correct dose of a medication compared to the baseline period ($p < 0.0001$). There was a statistically significant improvement in the percentage of correct doses in seven medications and a non-statistically significant improvement in the percentage of correct doses in four medications between baseline and Field Guide study period with no change in two medications which were given 100% correct in both time periods (Table 2). During the Field Guide study period, the following medications had 100% appropriate dosing: intravenous (IV) adenosine, IV dextrose 10%, intramuscular (IM) diphenhydramine, IV/intraosseous epinephrine 1:10,000, IM glucagon, intranasal (IN)/IV naloxone, and oral ondansetron. Most medications had only one indication per the Field Guide (Table 2).

Incorrect doses were given in 10.6% (51/483) medication administrations. Overdoses accounted for 4.4% (21/483) of medication administration errors compared to 31% (85/274) in the baseline period ($p < 0.0001$). The largest overdose during the study period was a single administration of three times the appropriate dose of solumedrol. There were four instances where patients received twice the appropriate dose of fentanyl. The most overdosed medications were IN midazolam (2/17, 11.8%) and IV fentanyl (11/117, 9.4%) (Table 3). Underdoses accounted for 6.2% (30/483) of medication administration errors and 17.8% (49/274) during the baseline period ($p < 0.001$). The largest underdose occurred when a patient received a 10-fold underdose of IM epinephrine 1:1000. The most underdosed medications during the study period were IN midazolam (4/17, 23.5%) and IM epinephrine 1:1000 (2/16, 12.5%) (Table 3). The highest percentage of errors was seen in the zero to one-year-old age group with 20% (3/15) of doses incorrect (Table 4).

Discussion

Our study demonstrated a high percentage of correct doses (89.4%) reportedly administered in children after implementation of the Field Guide with pre-calculated doses in mL during the two-year study period compared to our baseline percentage of 51.1%. Simulation literature has demonstrated decreased errors in medication administration when a volume-based field guide is utilized to calculate dosing (4, 8). However, no prior studies have evaluated the effectiveness of a field guide system at reducing pediatric medication dosing errors in the clinical setting. A strength of our study is we evaluated nearly all medication administered to children less than 13 years of age, excluding only nebulized and medications administered after medical direction, to better capture the scope of prehospital provider practice. The high percentage of correct medication doses following introduction of a volume-based field guide system demonstrates the

Table 1. Patient demographics.

Drug (Route)	Baseline 1/2014-12/2014 n = 206	Field Guide Study Period 8/2017-7/2019 n = 375	*p* value
Median Age in Years (IQR)	8.9 (4.2, 11.2)	8.2 (3.8, 10.8)	0.19
Male Gender (%)	126 (61)	218 (58)	0.48
Race*	n/a		
African American (%)		65 (17)	
Asian (%)		19 (5)	
Native Hawaiian or Other Pacific Islander (%)		1 (<1)	
White (%)		266 (71)	
Unknown (%)		24 (7)	
Ethnicity: Latinx* (%)	n/a	127 (34)	

*Race and ethnicity were not consistently documented in the ePCR in 2014.

Table 2. Comparison of correct doses by medication between baseline (2014) and the Field Guide study period (8/2017-7/2019) with medication indication per the field guide.

Drug (Route)	Baseline Correct Doses/ Total Doses (%)	Field Guide Study Period Correct Doses/ Total Doses (%)	*p* value	Medication Indication Per The Field Guide
Adenosine (IV)	n/a	1/1 (100)	n/a	Supraventricular Tachycardia
Dextrose 10% (IV)	2/2 (100)	4/4 (100)	0.67	Hypoglycemia
Diphenhydramine (IM)	13/14 (93)	18 (100)	0.82	Anaphylaxis/ Allergic Reaction
Diphenhydramine (IV)	17/20 (85)	26/27 (96)	0.17	Anaphylaxis/ Allergic Reaction
Epinephrine 1:1000 (IM)	4/13 (41)	14/16 (88)	0.002	Anaphylaxis/ Allergic Reaction
Epinephrine 1:10,000 (IV/IO)	9/22 (31)	20/20 (100)	<0.0001	Cardiac Arrest
Fentanyl (IN)	19/52 (37)	63/76 (83)	<0.0001	Pain
Fentanyl (IV)	46/91 (51)	101/117 (86)	<0.0001	Pain
Glucagon (IM)	n/a	2/2 (100)	n/a	Hypoglycemia
Methylprednisolone (IV)	5/9 (56)	23/24 (96)	0.004	Anaphylaxis/ Allergic Reaction/Asthma
Midazolam (IM)	2/17 (12)	35/41 (85)	<0.0001	Status epilepticus/seizure
Midazolam (IN)	3/7 (43)	11/17 (65)	0.32	Status epilepticus/seizure
Midazolam (IV/IO)	8/13 (62)	57/62 (92)	0.003	Status epilepticus/seizure
Naloxone (IN/IV)	1/1 (100)	2/2 (100)	0.71	Suspected opioid overdose/poisoning
Ondansetron (IV)	11/13 (85)	23/24 (96)	0.23	Severe nausea/intractable vomiting
Ondansetron (oral)	n/a	32/32 (100)	n/a	Severe nausea/intractable vomiting

utility of this strategy to reduce medication errors in the prehospital setting.

Advantages to the Field Guide system include a customized preprinted medication guide based on the institution's formulary that gives providers the weight-based dose along with the appropriate volume in mL. It is color-coded by weight and age for ease of provider use (8). An example page from the Field Guide can be found in Appendix A. A simulation study demonstrated that the Handtevy™ LBT system was superior to the Broselow LBT in terms of correct

Table 3. Comparison of overdosing and underdosing by medication between baseline (2014) and the Field Guide study period (8/2017-7/2019).

Drug (Route) n	Correct Doses (%)	Overdoses (%)	Mean Percentage of Overdose (sd)	Underdoses (%)	Mean Percentage of Underdose (sd)
Adenosine (IV)					
Baseline (n = 0)	n/a	n/a		n/a	
Field Guide Study Period (n = 1)	1 (100)	0	–	0	–
Dextrose 10% (IV)					
Baseline (n = 2)	2 (100)	0	_	0	_
Field Guide Study Period (n = 4)	4 (100)	0	–	0	–
Diphenhydramine (IM)					
Baseline (n = 14)	13 (93)	0	_	1	31%
Field Guide Study Period (n = 18)	18 (100)	0	–	0	–
Diphenhydramine (IV)					
Baseline (n = 20)	17 (85)	1	133%	2	61% (11)
Field Guide Study Period (n = 27)	26 (96)	1	47%	0	–
Epinephrine 1:1000 (IM)					
Baseline (n = 13)	4 (41)	3	48% (3)	6	63% (6)
Field Guide Study Period (n = 16)	14 (88)	0	–	2	62% (41)
Epinephrine 1:10,000 (IV/IO)					
Baseline (n = 22)	9 (31)	13	146% (93)	0	_
Field Guide Study Period (n = 20)	20 (100)	0	_	0	_
Fentanyl (IN)					
Baseline (n = 52)	19 (37)	31	99% (57)	2	68% (7)
Field Guide Study Period (n = 76)	63 (83)	4	34% (10)	9	47% (8)
Fentanyl (IV)					
Baseline (n = 91)	46 (51)	31	122% (76)	14	51% (16)
Field Guide Study Period (n = 117)	101 (86)	11	88% (60)	5	39% (8)
Glucagon (IM)					
Baseline (n = 0)	n/a	n/a	_	n/a	_
Field Guide Study Period (n = 2)	2 (100)	0	–	0	–
Methylprednisolone (IV)					
Baseline (n = 9)	5 (56)	2	124% (88)	2	40% (10)
Field Guide Study Period (n = 24)	23 (96)	1	150%	0	–
Midazolam (IM)					
Baseline (n = 17)	2 (12)	2	56% (0)	13	44% (14)
Field Guide Study Period (n = 41)	35 (85)	1	47%	5	61% (24)
Midazolam (IN)					
Baseline (n = 7)	3 (43)	0	_	4	55% (12)
Field Guide Study Period (n = 17)	11 (65)	2	46% (6)	4	62% (14)
Midazolam (IV/IO)					
Baseline (n = 13)	8 (62)	2	95% (5)	3	53% (6)
Field Guide Study Period (n = 62)	57 (92)	1	60%	4	70% (18)
Naloxone (IN/IV)					
Baseline (n = 1)	1 (100)	0	_	0	_
Field Guide Study Period (n = 2)	2 (100)	0	–	0	–

(*continued*)

Table 3. Continued.

Drug (Route) n	Correct Doses (%)	Overdoses (%)	Mean Percentage of Overdose (sd)	Underdoses (%)	Mean Percentage of Underdose (sd)
Ondansetron (IV)					
Baseline (n = 13)	11 (85)	0	_	2	50% 0
Field Guide Study Period (n = 24)	23 (96)	0	–	1	75%
Ondansetron (oral)					
Baseline (n = 0)	n/a	n/a		n/a	
Field Guide Study Period (n = 32)	32 (100)	0	–	0	–

Table 4. Appropriate dosing, underdosing, and overdosing by age group.

Age in years (total number of medications given)	Number of correct doses (%)	Number of overdoses (%)	Number of underdoses (%)
0 n = 15	12 (80)	1 (7)	2 (13)
1 n = 33	32 (97)	0	1 (3)
2 n = 26	23 (88)	1 (4)	2 (8)
3 n = 29	28 (97)	1 (3)	0
4 n = 30	26 (86)	2 (7)	2 (7)
5 n = 31	27 (87)	1 (3)	3 (10)
6 n = 25	22 (88)	0	3 (12)
7 n = 30	26 (87)	1 (3)	3 (10)
8 n = 29	29 (100)	0	0
9 n = 46	41 (89)	4 (9)	1 (2)
10 n = 48	42 (88)	3 (6)	3 (6)
11 n = 65	53 (82)	6 (9)	6 (9)
12 n = 76	71 (94)	1 (1)	4 (5)

dose for dextrose and time to administration in prehospital simulation scenarios although there was no difference between the performance of prehospital providers between the two different LBT systems for epinephrine dosing. Post-scenario surveys of study participants identified a strong preference for the Handtevy^{TM} system over the Broselow tape, despite their relative unfamiliarity with it (9).

The Field Guide system specifically addresses two potential sources of cognitive error identified by Lammers: difficulty with calculations under stress and the conversion of medications from weight-based dosing in milligrams per kilogram to volume in mL (2). After introduction of a state-wide pediatric dosing reference similar to the Field Guide but with dilution requirements, Hoyle found 31.2% of doses were incorrect in simulation scenarios (4). Eliminating the need for dilution may be an important adjunct in reducing pediatric medication errors.

The four most frequently incorrectly dosed medications were IN midazolam (35%), IN fentanyl (17%), IM midazolam (15%) and IV fentanyl (14%). Of note, the only indication for midazolam administration in our field guide is seizures. Previous studies have documented incorrect dosing of benzodiazepines (44–60% incorrect) (2, 4) and opioid medications (36% incorrect) (4). The more frequent incorrect doses of these two controlled substances is concerning given the possible safety consequences of an overdose and lack of therapeutic benefit of an underdose. It is not entirely clear why there were more frequent errors in these medications although they were the two most frequently administered medications during the study period (193 fentanyl doses and 120 midazolam doses). It is possible that the underdoses, which were more common, were a paramedic's attempt to start with a lower dose and titrate upwards to a therapeutic level. Paramedics may also not be as comfortable with increasing the dose appropriately for nasal atomization dosing in pediatric patients. Providing prompt pain relief for acutely injured children (15) and prompt treatment for seizures (16) is important in their management, and we plan to continue to encourage our paramedics to use these medications while further investigating ways to improve their dosing accuracy.

Medications were administered more frequently to older children than to younger children. This is likely due to several factors including prehospital medications are more frequently indicated in older children, and a possible decreased level of comfort in treating young children. There was variability in medication errors by patient age. Infants less than one year of age had the highest percentage of incorrect doses (20%). However, there was not a clear trend between the frequency of errors and patient age, leading us to believe that utilizing the Field Guide was helpful for pediatric patients regardless of age.

Limitations

Our study had several limitations. First, this study reflects a single center's experience. The baseline data from 2014 was extracted from a different EMS electronic reporting software system. Some of the medications with 100% accuracy were administered infrequently (e.g. adenosine was administered once). Our dosing errors may have been impacted by underreporting since medication administration was not directly observed as occurs during simulation. A paramedic may have administered the incorrect dose although he or she thought the dose was correct, and this error would not have been detected. However, our EMS system uses a robust quality improvement process emphasizing a culture of safety for reporting errors, and we have consistently found that the record typically reflects the call. We also were not able to evaluate if the paramedic used the LBT correctly. The Broselow LBT more closely approximates weight compared to the Handtevy LBT when evaluated using national survey data (17).

Conclusion

After implementation of a precalculated mL dose system by patient age for EMS providers, most pediatric medications were reportedly administered within the appropriate dose range. A field guide with precalculated dose (in mL) may be an effective tool for reducing pediatric medication dosing errors by EMS providers.

Future Directions

Future studies will be focused on validating these results in other EMS systems, including fire-based systems, systems of various sizes, and systems with variability in provider training (i.e. EMT-Basic, EMT-Advanced, Paramedic, and Critical Care Paramedic). Future studies will also investigate the effect on patient outcomes following incorporation of pediatric equipment sizing using the Field Guide system.

Disclosure Statement

The authors report no conflict of interest.

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Appendix A. Example Page from Handtevy™ Field Guide System

OPTION 1 -ESTIMATE AGE USING LENGTH
-USE PROVIDED TAPE MEASURE (HEAD TO HEEL)
OPTION 2 -USE ACTUAL AGE (IF STANDARD SIZED CHILD)

7 YR

EMS STUDY				IDEAL WEIGHT 25 KG	
DRUG	CONC	VOL	RT	DOSE/KG	AMNT
Adenosine [1st]	6 mg/2mL	0.83 mL	IV/IO	0.1 mg/kg	2.5 mg
Adenosine [2nd]	6 mg/2mL	1.7 mL	IV/IO	0.2 mg/kg	5 mg
Albuterol	2.5 mg/3mL	3 mL	Neb	Dose =	2.5 mg
Atrovent	0.5 mg/2.5mL	1.25 mL	Neb	Dose =	0.25 mg
Amiodarone	150 mg/3mL	2.5 mL	IV/IO	5 mg/kg	125 mg
Ativan	2 mg/mL	1 mL	IV/IM/IO	Dose =	2 mg
Atropine	1 mg/10mL	5 mL	IV/IO	0.02 mg/kg	0.5 mg
Benadryl	50 mg/mL	0.5 mL	IV/IM/IO	1 mg/kg	25 mg
Bicarb 8.4%	50 mEq/50mL	25 mL	IV/IO	1 mEq/kg	25 mEq
Calcium Chloride	1 G/10mL	5 mL	IV/IO	20 mg/kg	500 mg
D25W	(D50W - 25 mL) + 25 mL NS	50 mL	IV/IO	0.5 G/kg	12.5 G
Epi 1:1,000 IM	1 mg/mL	0.25 mL	IM	0.01 mg/kg	0.25 mg
Epi 1:10,000 IV	1 mg/10mL	2.5 mL	IV/IO	0.01 mg/kg	0.25 mg