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Learning in practice

Prospective observational study on the incidence of medication errors during simulated resuscitation in a paediatric emergency department

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Abstract

Objectives To characterise the incidence and nature of medication errors during paediatric resuscitations.
Design A prospective observational study of simulated emergencies.
Setting Emergency department of a tertiary paediatric hospital.
Participants Teams that included a clinician who commonly leads "real" resuscitations, at least two assisting physicians, and two or three paediatric nurses.
Interventions The teams conducted eight mock resuscitations, including ordering medications. Exercises were videotaped and drugs ordered and administered during the resuscitation were recorded. Syringes and drugs prepared during the resuscitation were collected and analysed for concentrations and actual amounts.
Main outcome measures Number and type of drug errors.
Results Participants gave 125 orders for medications. In 21 (17%) of the orders the exact dose was not specified. Nine dosing errors occurred during the ordering phase. Of these errors, five were intercepted before the drug reached the patient. Four 10-fold errors were identified. In nine (16%) out of 58 syringes analysed, measured drug concentrations showed a deviation of at least 20% from the ordered dose. A large deviation (at least 50%) from the expected dose was found in four (7%) cases.
Conclusions Medication errors commonly occur during all stages of paediatric resuscitation. Many errors could be detected only by analysing syringe content, suggesting that such errors may be a major source of morbidity and mortality in resuscitated children.

Introduction

Medication errors are a common cause for iatrogenic adverse events.[1] They can lead to severe morbidity, prolonged hospital stay, unnecessary diagnostic tests, unnecessary treatments, and death.[1–5] Such errors commonly involve children.[6] In a recent study we found that 10% of the children treated in the emergency department were subjected to medication errors.[7] The risk of errors was greater when a drug was ordered by a trainee and in patients with severe rather than mild disease.

In children, dosing errors are the most common type of errors,[7] with the most common cause being the calculation of doses.[8] In a written survey among 34 physicians in England, more than half gave the incorrect answers when questioned about the appropriate dose of adrenaline (epinephrine) for asystole in a child.[9]

Resuscitation is an extremely stressful and uncontrolled situation for medical staff. Physicians must respond promptly to the needs of an unstable patient, often with limited information. The need to calculate drug doses under these conditions is challenging. We hypothesised that the lack of appropriate time, coupled with the lack of focus on dose calculation because of competing activities, may lead the physician who calculates the drug doses and the nurse who prepares them to make mistakes that are potentially lethal for the patient. The incidence of medication errors during paediatric resuscitation and the impact of such errors on patients' outcome are currently not known. We examined the incidence and nature of such errors in simulated resuscitation of children.

Methods

This prospective observational study was conducted in the emergency department of a tertiary paediatric hospital affiliated with a university.

From September 2001 to May 2002, fellows, residents, and nurses participated in mock resuscitations, which are part of routine emergency department educational rounds. Participants knew they were taking part in a research project but not the exact nature of the study. A paediatric emergency physician experienced in conducting mock resuscitations served as a moderator for the cases. For each round a different case scenario (based on actual cases treated in the department) was presented (box and table 1). The moderator started the scenario with a clinical description of the patient's condition and continued to provide clinical data, in response to physicians' and nurses' actions, throughout the case. To simulate real life, an age appropriate mannequin was used. A team that included a leader (a fellow in paediatric emergency medicine or a senior resident in paediatrics or emergency medicine), at least two assisting physicians (residents or fellows), and two or three paediatric nurses managed each case.

The responsible physician conducted a full resuscitation, including ordering drugs. According to the team leader's decision, other physicians on the resuscitation team could also order drugs or calculate doses. The use of standard references such as the hospital formulary, resuscitation cards, handheld computers, and calculators was allowed. (The Broselow paediatric emergency tape and colour coded materials, which at that time were not part of the routine equipment in the department, were not used.) The nurses assigned to the "patient" and the

Table 1 Scenarios used in mock resuscitations for study of medication errors

Case No	Age	Presenting signs and symptoms
1	4 months	Non-responsive, bradypnoea, shock (see box for details)
2	3 weeks	Seizures, hypoglycaemia, cardiorespiratory arrest
3	6 years	Fell from bike, fracture of forearm, narrow complex tachycardia
4	2 years	Upper airway obstruction, respiratory failure
5	3 months	Wheezing, respiratory failure
6	4 years	Status epilepticus, respiratory failure
7	3 years	Respiratory distress, decreased level of consciousness, vomiting
8	13 years	Cardiopulmonary arrest

physicians prepared the drugs and administered them according to the orders. One of the nurses was assigned to prepare drugs; other nurses and the physicians also prepared drugs if and when the designated person was busy. Individual and group feedback was given immediately after the mock resuscitation.

Documentation of drug administration

Three observers (two physicians and a pharmacist from the research team) recorded on a standard form all the orders and all drugs and fluids administered during the exercise. Each observer was located in a different position in the resuscitation room and focused on the actions of different team members. The scenarios were video recorded professionally. Subsequently, a team of physicians and a pharmacist viewed the tapes to assure the accuracy of the collected data. In cases of discrepancy between the data collected during the resuscitation and the events seen on the tape, the tape was considered to be correct. In cases of disagreement the reviewers discussed the case and resolved issues by consensus.

All syringes and drugs prepared during the resuscitation were collected and marked. The actual drug content and drug concentration in the syringes were analysed in the laboratory to compare them with the presumed drugs and concentrations ordered.

Definition of drug error

We considered the following as medication errors[7]: a medication that was ordered but not given (unless the order was cancelled), a medication that was given but not ordered, a drug given in a dose different by at least 20% from the recommenced dose, administration of a drug by an incorrect route, and a drug ordered that is not indicated for the patient's condition. The references for correct practice and drug doses were the hospital resuscitation card and formulary. For the purpose of the study we did not consider the failure to order a drug that was necessary for the patient's condition as an error as that may reflect a medical error or lack of knowledge and not necessarily a medication error.

One of the case scenarios used in the study

A 4 month old baby presented to the emergency department after his parents noticed that he was not responsive. The parents mentioned he had been febrile during the past 24 hours. On arrival to the emergency department the baby looks very sick. He is placid and mottled. The airway is patent, his respiratory rate is 10 per minute, the heart rate is 160 beats/min. Oxygen saturation cannot be measured, capillary refill time is four seconds. He is given oxygen, and bag and mask ventilation is started. Glucose concentration is checked and found to be normal. Fluid bolus is given. Broad spectrum antibiotics are administered. The baby's capillary refill, pulse, and blood pressure does not improve. He is intubated with rapid sequence intubation. Focal seizures develop, and he becomes bradycardic. Chest compressions and adrenaline (epinephrine) are started.

Laboratory analysis

The drug monitoring laboratory measured concentrations of glucose, calcium, and bicarbonate (Vitros 950 Chemistry Analyzer, Ortho-Diagnostics, Rochester, USA), sodium (flame photometry, IL 943, Instrumentation Laboratory), chloride (CMT10 Chloride Titrator), hydrocortisone (Immuno 1, Bayer, Terrytown, New York, USA), and dopamine and adrenaline (high performance liquid chromatography with reagents supplied by Bio-Rad Laboratories, Hercules, CA, USA). Quantitation was performed on weak cation exchange silica, and compounds were detected by their electrochemical activity. All other drugs (lorazepam, atropine, midazolam, lidocaine) were measured by automated high performance liquid chromatography with a drug profiling system (Bio-Rad REMEDi-HS) after calibration with pure standards.

Results

We conducted eight mock resuscitations in which 20 physicians and 15 nurses took part. Participants initiated 125 orders for drugs. In 24 cases the same order was repeated more then once. In 17 cases we were unable to determine whether or not the drug was given. In 12 cases the ordered drug was not administered. Seventy two drugs were given, and 58 syringes were analysed for content. We identified medication errors in seven of the eight mock resuscitations.

Incomplete orders

In 21 (17%) of the orders the exact dose was not specified (for example, "prepare another dose of epinephrine," "please give the patient fluids," etc). In only 52 orders (41%) was the route of administration specified.

Dosing errors

Nine dosing errors occurred during the ordering phase (table 2). Of these, there were three 10-fold errors (see below). In four cases the dose ordered was higher than the recommended dose and in five cases it was lower. We did not identify any error in the doses of resuscitating fluids. Identifiable causes of errors included ordering of a total daily dose of vancomycin as a single dose and ordering the wrong concentration of dextrose. Of these errors, five were intercepted before the drug reached the patient.

We identified a total of four 10-fold errors: three at the ordering phase and one at the administration phase. All these errors were intercepted before the drug reached the patient.

Errors in preparation and administration

Several errors occurred during preparation and administration of the drugs. One nurse prepared a 10-fold higher dose of midazolam. The charge nurse identified the error before the drug was given. One drug was given via the wrong route—that is, oral paracetamol suspension was administered rectally. In one case racemic adrenaline was ordered but L-adrenaline was given via a nebuliser. Racemic adrenaline was not available during the study period. Because there are large differences in the recommended doses for racemic versus L-adrenaline, we considered it as an error (the dose was not specified when the drug was ordered and we could not verify the dose that was given).

Table 2 Dosing errors during ordering phase in mock resuscitations

Case No	Weight (kg)*	Drug	Correct dose†(dose per kg)	Ordered dose(dose per kg)
1	7	Succinylcholine (suxamethonium)	7-14 mg (1-2 mg)	1.4 mg (0.2 mg)
1	7	Mannitol	3.5-7.0 g (0.5-1.0 g)	0.40 g (0.06 g)
4	12	Atropine	0.12-0.24 mg (0.01-0.02 mg)	0.010 mg (0.001mg)
5	5	Adrenaline	0.05 mg (0.01 mg)	0.16 mg (0.03 mg)
4	12	Midazolam	0.6-2.4 mg (0.05-0.20 mg)	0.50 mg (0.04 mg)
4	12	Vancomycin	180 mg (15 mg)	600 mg (50 mg)
2	4	Dextrose 50%‡	20-40 ml dextrose 10% (0.5-1.0 g)	4 ml (1 ml)
5	5	Salbutamol§	0.30 ml (0.03 ml)	0.15 ml (0.03 ml)
4	12	Atropine	0.12-0.24 mg (0.01-0.02 mg)	0.400 mg (0.033 mg)

*Weight was provided by moderator at beginning of mock resuscitation.
†See text for the definition of correct doses
‡Use of 50% dextrose in neonate was considered an error.
§Salbutamol 5 mg/ml solution for inhalation. Minimum recommended dose for acute bronchospasm is 0.3 ml.

Expected *v* actual syringe content

Seventy two drugs were given, and the therapeutic drug monitoring laboratory analysed 58 syringes. Fourteen syringes were not analysed because they contained drugs our laboratory could not analyse (succinylcholine (suxamethonium), ceftriaxone, and adenosine). In nine syringes (16%) the laboratory identified a deviation of at least 20% from the expected dose (table 3). In four cases (7%) the deviation from the expected dose was large (at least 50%). These included a twofold higher dose of midazolam, a threefold higher dose of lorazepam, a 25-fold lower dose of hydrocortisone, and a twofold lower dose of atropine.

Discussion

In a model of simulated paediatric resuscitation, we identified frequent and potentially serious medication errors. These errors occurred at all stages of resuscitation including ordering, preparing, and administering drugs. Both physicians and nurses made errors. We also found that some errors, including potentially lethal errors, were intercepted by a team member and that several errors could be detected only when the content of the syringe was analysed.

Full cardiopulmonary arrest in children is associated with high mortality and morbidity.[10] If one assumes that drugs given during resuscitation have beneficial effects on outcome, it is logical to assume that preventing errors will improve survival and the rates of full neurological recovery. Maybe even more serious is that major drug errors may be missed if the child dies because it is not suspected that the drugs actually caused or contributed to the morbidity and mortality.

Shah and colleagues also used simulated resuscitation to study medication errors in a paediatric emergency department.[11] Participants were randomised a standard dosing system (Broselow tape) or traditional dosing references. The Broselow paediatric emergency tape and colour coded materials was associated with lower deviation from the recommended dose range. There are several differences between that study and our current one. In our study a team of physicians and nurses ordered, prepared, and administered the drugs as in the real life situation. In the study by Shah et al only one participant at a time ordered drugs, and the researchers studied only the ordering stage of the complex process of giving drugs during resuscitation.[11] For obvious ethical reasons, this study could not be performed on real life resuscitations. Therefore, the design of our study, which used simulated resuscitations, represented the closest possible alternative to identify and characterise medication errors in real resuscitations. Shah et al also did not specify how errors were detected and did not verify the contents of the syringes.[11]

Table 3 Deviation from expected dose in analysed contents of syringes

Drug	No of syringes analysed	No with discrepancy*
Electrolytes	16	0
Glucose	4	0
Anticonvulsants	10	3
Amines	20	3
Atropine	4	2
Others†	4	1
Total	58	9

*More than 20% discrepancy between expected content and content found in syringe.
†Including two syringes of lidocaine, one syringe of hydrocortisone, and one dose of paracetamol.

Specific errors

In our study physicians often gave incomplete orders (for example, no specific route of administration), though none of these resulted in a drug given by the wrong route. Errors were probably avoided because well trained members of the resuscitation team interpreted such orders correctly. It is not clear whether such orders would be interpreted correctly by less well trained members. When an incomplete order did not specify the exact dose it caused delay in the administration. In most of these cases, physicians had to specify the dose after the nurse asked for clarifications. Such delays could have detrimental effects during resuscitation, when every second counts.

In eight mock resuscitations we found a large number of errors. Possible explanations for this were the use of drugs that physicians did not order on a daily basis and the need to order drugs and calculate doses in a busy and stressful environment.

We identified four 10-fold errors in 125 orders for medication. This incidence was substantially higher than previously reported, in studies based on incidence reports[12] and retrospective chart reviews[6 7] and in simulated resuscitation.[11] We previously audited more than 1500 charts in the emergency department and detected only two 10-fold errors.[7] Hence, during resuscitation the rate of 10-fold errors is in the order of 24-fold higher. Errors of this magnitude may occur more commonly in children because the dose per kilogram for some of the drugs is extremely small, which results in a low total dose.[13] In our study three of the four 10-fold errors resulted in a lower dose being ordered, indicating that mistakes in calculation or misplacement of the decimal point caused the error.

Detection and prevention of medication errors

Improved communication within the team could reduce medication errors.[14] Indeed, many of the important errors in our study were intercepted by a team member. Team work also compensated for incomplete orders and enabled the team to prepare

and administer the drug despite the lack of specific instructions. We suggest that every paediatric emergency department should have a system for regular training of physicians and nurses to work as a team during resuscitations.

The results from studies on medication errors vary depending on methods and the definition of errors. For example, voluntary reporting of medication errors will detect fewer errors than a detailed review of charts.[12 15] Studies of medication errors using an observer[16] may detect some errors that would not be detected by voluntary reporting or chart review. Analysis of syringe contents may reveal errors that could not be detected in other ways. Parshuram et al analysed morphine infusions in the paediatric and neonatal intensive care units of a tertiary paediatric centre.[17] They found discrepancies of at least 10% between ordered and measured concentrations in over two thirds of infusions.

As our study clearly shows, discrepancies between the ordered drug and syringe contents occur even under close observation. The finding that in 15% of cases there was a considerable discrepancy between the expected and actual content of the syringes suggests that the incidence of medication errors in sick children might be substantially higher than previously estimated.

Various strategies have been suggested to reduce drug errors, including the use of a computerised system in which the physician places orders by using a computer program,[18 19] having a clinical pharmacist review orders,[20] and the use of a unit dose system. However, these strategies are not practical during resuscitation. A standard dosing system (Broselow tape) can significantly reduce errors during the ordering phase,[11] and the use of such systems should be encouraged.

Limitations

Our study has several potential limitations. This design cannot be used to study medication errors in real resuscitations as it is impossible to conduct a study in which all drugs administered to patients during resuscitations are recorded and analysed in a meticulous way. It is not clear whether one can extrapolate the data from our model to real patients. Yet, this experimental model gave us the opportunity to analyse the actual syringe contents of the drugs given and to detect discrepancies that could not be detected in real resuscitations. Because observers were located in different positions in the resuscitation room we did not try to assess interobserver reliability or the differences between the data collected by the observers and the data seen on the videotape.

Our model could not adequately simulate the emotional stress and other factors such as fatigue, which may occur during real resuscitation. Moreover, because the scenarios were videotaped participants may have tried harder to perform their best. Hence, the rate of drug errors identified by us could be lower than the actual incidence during real life resuscitations.

Since the completion of the study we have put emphasis on drug doses in real life resuscitations and mock code scenarios. The Broselow tape and resuscitation carts are now used during resuscitations. Drugs are given from the cart on the basis of the estimated weight of the child, with a colour coded system. We also increased the number of mock codes to give trainees more opportunities to practise resuscitation and developed and implemented a formal teaching programme on the use of sedation and intubation drugs for staff and trainees. Further studies are needed to determine whether these changes have reduced the number of medication errors during resuscitation.

What is already known on this topic

Medication errors are common in paediatric emergency departments

The incidence of medication errors during paediatric resuscitation has not been fully investigated

What this study adds

Frequent and potentially serious medication errors occur at all stages of paediatric resuscitation

Many errors could be detected only by analysis of syringe content, suggesting that the incidence of medication errors during resuscitations is substantially higher than previously estimated

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Contributors: EK, SK, DAJ, CP, and GK designed the study. EK, WS, CP, and DAJ observed the mock resuscitations and analysed the videotapes. ZV was responsible for the laboratory analysis. EK drafted the study report, which was reviewed by all authors. All authors read and approved the final draft. EK and GK are guarantors.

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