ASSESSING FOR PREPARATION AND ADMINISTRATION ERRORS: A PROSPECTIVE OBSERVATION STUDY OF PAEDIATRIC RESUSCITATION SIMULATIONS

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ABSTRACT

Introduction

Very few studies have assessed drug preparation and administration errors during paediatric resuscitation. Current evidence suggests that medication errors in paediatrics is a serious problem. The aim of this study was to evaluate drug preparation and administration errors incurred during the simulated resuscitation of paediatric patients.

Methods

This was a prospective observational study performed in the emergency department of a tertiary level hospital . Teams consisting of two emergency doctors were tasked with preparing and delivering medication during simulated emergency scenarios. Preparation processes were video recorded. All vials, syringes and administered volumes were collected and analysed to determine the accuracy of drug preparation and delivery. Deviations from intended volumes were calculated.

Main Results

A total of 96 dosages were recorded from 24 participants. Most errors were identified in the withdrawal of drugs phase (prior to dilution) (13 of 95 doses had a >20% error), and the administration of medications phase (20 of 96 doses had a >20% error). Overall the median time taken to deliver each drug was 79 seconds (IQR 59, 100 seconds). The largest percentage errors were seen when a large syringe was used to withdraw or administer a small volume of medication.

Conclusion

The study clearly demonstrated that there were significant errors in the preparation and administration of medication. Training in the preparation and administration of paediatric medications should be available for all emergency nurses and doctors. Correct syringe choice may reduce these errors. Smaller syringes should be used for withdrawing or administering smaller volumes.

INTRODUCTION

Medication errors during emergency situations are 39 times more likely to lead to harm and 51 times more likely to result in death when compared to non-emergency situations [1]. In addition to the severe morbidity and mortality caused by these errors they have also been associated with prolonged hospital stays, unnecessary diagnostic tests and unnecessary treatments [2-5]. While there has been considerable research about medication errors in general, limited research has been done on these errors during resuscitation situations within the emergency department.

Time is an important consideration during a resuscitation. Medications in resuscitation situations are often lifesaving and are required promptly. There have been very few studies looking at the specific times taken to prepare medications. A useful tool in reducing time to administration is the utilization of colour-coded syringe systems. These systems, which consist of pre-marked syringes based on the weight of the patient, simplify the withdrawal of medications and result in a decrease in time to administration [6,7,8]. It is yet to be determined whether these systems would reduce the errors in the actual amounts administered to patients. In addition, these colour-coded syringes are currently not commercially available.

Existing studies on medication errors during resuscitations have focused on paediatric populations, given that this group is particularly vulnerable to medication errors [6]. A large proportion of these studies have looked at dosing errors, with only a few studies evaluating the errors arising from the preparation and administration of medications

during resuscitations. One study looking at the types of medication errors made by nurses in paediatric resuscitations, measured the volumes of diluent used to create a solution in order to determine if there were any errors. [9] A study by Kozer et al (2004) looked at the incidence of medication errors in paediatric mock resuscitations and collected prepared medications intended for administration in order to analyse the content and determine drug concentrations [10]. Actual volumes of medications administered were not assessed thus the actual amount of drugs administered could not be assessed. In addition the stages at which these errors occurred were not adequately assessed. There is yet (to our knowledge) no comprehensive study that has assessed for errors occurring during the preparation and administration phase of medication delivery during resuscitations.

The aim of this study was to evaluate medication preparation and administration errors incurred during the simulated resuscitation of paediatric patients.

METHOD

Participants and setting

This was a prospective observational study conducted in the Simulation Laboratory of an academic hospital in Johannesburg, South Africa. The study, which included a total of 24 volunteer participants, consisted of Emergency Medicine Registrars, Emergency Department Medical Officers and Community Service doctors. The simulations were held in a high fidelity simulation laboratory using manikins capable of simulating real life resuscitations. The purpose of the immersive simulation environment was to replicate real-life resuscitation experiences in which participants would be required to prepare and administer medications. Permission to conduct the study was obtained from the University of the Witwatersrand Human Research Ethics Committee and written informed consent was obtained prospectively.

Study protocol

Participants were randomly allocated into 12 teams of two participants. A moderator, who also recorded times, introduced the scenario and gave a clinical description of the patient's condition including the patient's weight. The team then performed two resuscitation scenarios under the direction of the team leader. Each scenario required four intravenous drug administrations. Each team performed two different scenarios (Figure 1). The team leader ensured that roles of team members were rotated, thus ensuring that each participant prepared and administered four medication doses. The role of team leader was assumed by a member of the study team to ensure consistency of all medications and dosages. Thus the same medications were ordered in the same

order and at the same dosages for both scenarios, preventing the ordering of an incorrect medication or incorrect dosage which would be a prescription error rather than a preparation or administration error.

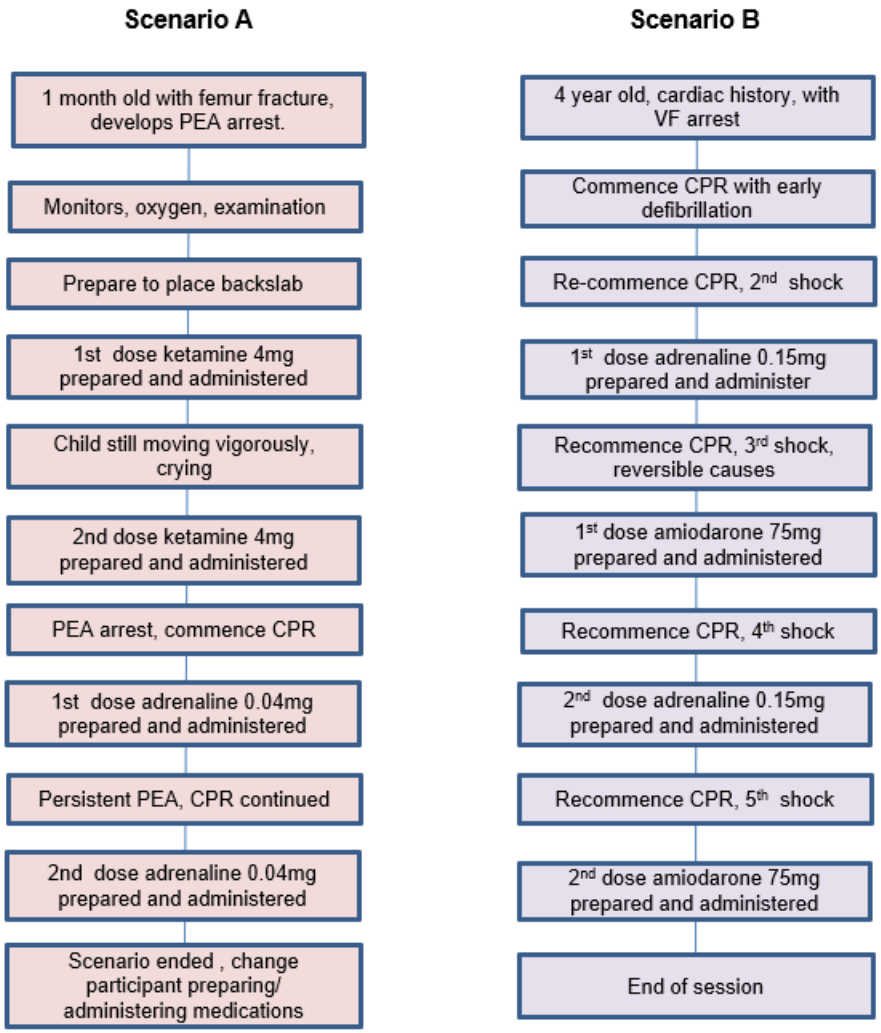

Figure 1 *– Scenarios A and B*

A member of the study team was present during the resuscitations, recording all intended volumes for the preparation and administration of the medications on a standardised form. Participants were instructed to explain how they intended to draw up the medications and diluents as well as the volumes they would be administering. These values were taken as intended volumes. A dedicated camera was focused on

the area assigned for the preparation of medication. Video footage was reviewed by an assessor of the study to determine the times taken from completion of dosage instruction to administration of medications. Times taken to administer medications were also recorded by a member of the study team. For three participants technical errors with video recording meant that the manual times recorded were used.

Data collection

Prior to performing the study all syringes and medication vials were weighed. Two sensitive scales capable of measuring weight to the nearest 0.01mg were used (Pocket scale, 200g/0.01g, Model: MH-200, CAMRY Electronic digital scale, 100g/0.01g, Model: EHA601). Normal saline was used in place of the actual drugs in the medication vials and was also used as the dilution fluid. All vials and syringes were weighed after the study; the average of the two readings was taken as the final reading. If a large difference was obtained, then the scales were recalibrated, and readings were repeated. Scale calibration was frequently tested using a standardised weight.

Calculation of volumes

Refer to Figure 2. The dilution volume was determined by measuring the difference in weight of the vials containing diluents before and after withdrawal. The volumes of medications withdrawn was calculated in the same way. Administered volumes were collected via a system involving multiple 3-way stopcocks, which allowed for collection of fluids in a syringe. The volume of the content of the syringes was calculated using the formula Volume= Mass/Density, where the density of normal saline was taken as 1.005g/ml [11]

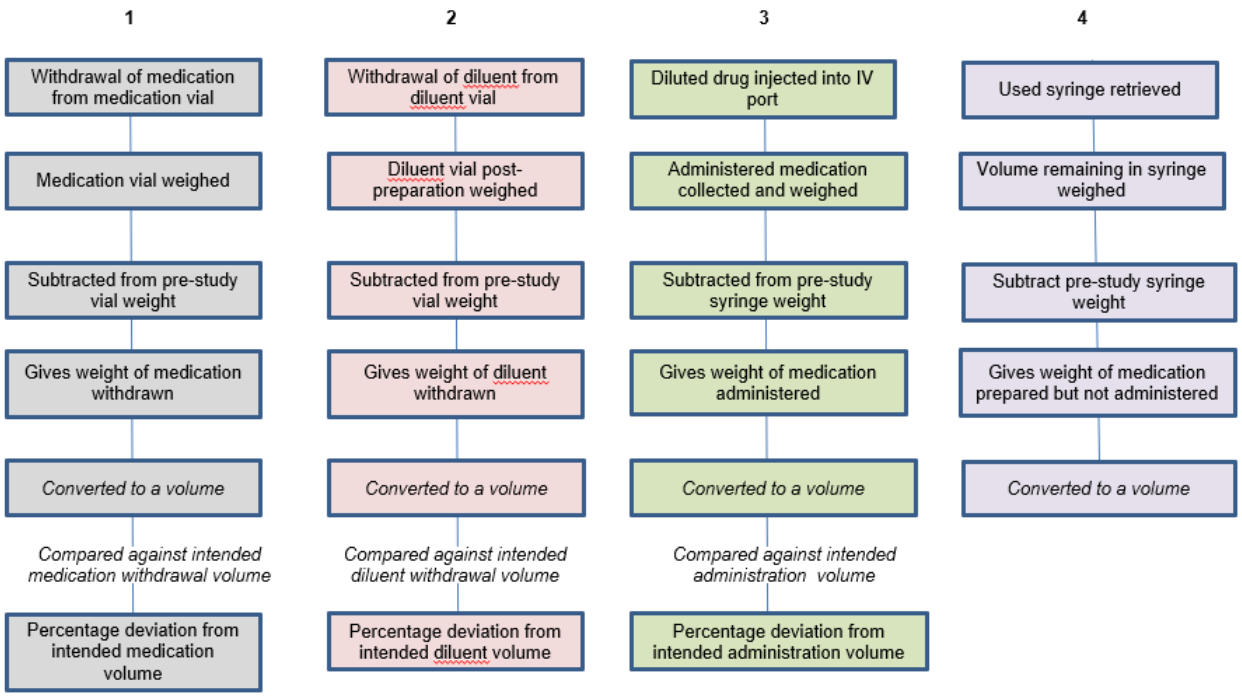

Figure 2 *– Volume calculations; calculation of total diluted medication volume(ml) = diluent (ml) + medication withdrawn (ml); calculation of spillage (ml) = total diluted medication volume – administered volume – un-administered volume*

Analysis

Actual volumes of medications withdrawn, diluent volumes withdrawn, total volume of medication plus diluent and administered volumes were all compared against the intended volumes. Since actual volumes and intended volumes varied greatly over the range of different dosages in the study, a percentage error analysis was preferred over actual differences. These errors were then categorized in the following subgroups:

- <10 %
- 10-20%
- 20-30%
- >30%.

Medians with interquartile ranges were calculated for all continuous data and percentage errors were calculated for all categorical data. Previously used standards deemed that a volume deviating by more than 10% should be considered as medication errors [6,12]. A higher deviation of 20% was used as a benchmark, it was felt that this value is more clinically relevant and accounts for any effects of technical measurement errors. The median time for each dose preparation was calculated. Spillage data for each drug is shown in Table 1.

Table 1: *Spillage Data*

Measurement	Overall	Adrenaline (4kg)	Ketamine	Adrenaline (15kg)	Amiodarone
Median (IQR) (ml)	0.19 (0.08;0.31)	0.29 (0.19;0.72)	0.19 (0.11;024)	0.2 (0.11;0.3)	0.12 (0.06;0.2)

RESULTS

Each of the 24 participants prepared and administered four drug doses, therefore a total of 96 dosages were recorded. In one of the adrenaline (4kg) doses the participant used a solution previously prepared, therefore only the administered volume could be used. The age, sex, designation, years of experience and courses attended by participants are listed in Table 2.

Table 2: *Characteristics of study participants*

Demographics (n=24)	
Male	12
Female	12
Number of years post graduation	
3 to 5	16
6 to 10	7
11 to 15	1
Designation	
Emergency Medicine Registrar	12
ED Medical Officer	8
Community Service doctor	4
Courses	
ACLS	23
PALS	17
Neonatal Resuscitation Course	14
APLS	1

Percentage Errors

Most errors were identified in the withdrawal of drugs phase (prior to dilution) (13 of 95 doses (13.7%) with >20% error), and the administration of medications phase (20 of 96 doses (20.8%) with >20% error) (See Table 3).

Drug withdrawal errors

Ketamine had the highest number of percentage error deviations of >30% from intended drug volumes, with 9 of the 24 participants making these errors (37.5%) (median 13%, IQR 0.5%, 35.9%). In three cases these deviations were very large (84%,150% and -60%). Most participants (20 of 24) opted to dilute a 10mg/ml solution of ketamine down to a 1mg/ml solution and then administer 4ml of this using a 10ml syringe. Two participants (4 doses) opted to withdraw 0.4ml directly from the vial using a 2ml syringe. In both cases there were large deviations of >30% from intended drug withdrawal volumes; one participant corrected this mistake by administering the correct amount. The other participant administered >30% more than was intended for both dosages.

With amiodarone, participants were required to remove 1.5ml of amiodarone directly from the vials, which was then administered. No deviations of >30% from intended drug volumes occurred. In 21 of the 24 dosages either a 5ml or a 2 ml syringe was used to withdraw and administer medications. A 10ml syringe was used to withdraw medications in the remaining 3 of 24 dosages.

Table 3 – Percentage of errors of actual volumes compared against intended volumes

Measurement	Percentage Error of Intended Drug Volumes					Percentage Error of Intended Dilution Volume				Percentage Error of Total Volume Withdrawn					Percentage Error of Volume Administered				
	Overall	Adrenaline (4kg)	Ketamine	Adrenaline (15kg)	Amiodarone	Overall	Adrenaline (4kg)	Ketamine	Adrenaline (15kg)	Overall	Adrenaline (4kg)	Ketamine	Adrenaline (15kg)	Amiodarone	Overall	Adrenaline (4kg)	Ketamine	Adrenaline (15kg)	Amiodarone
Median (IQR)(%)	5.5 (1.5;13.5)	7.5 (3.5,13.5)	13 (0.5,35.9)	6.5 (3.5;9.7)	1.8(0.2;6)	-3.9 (-7.1;-1.8)	-2.6 (-6.8;-2.7)	-4.1 (-8.1;-3.6)	-4.5 (-6.7;-1.5)	-1.5 (-4.9;1.2)	-1.8 (-5.89;-0.8)	-2.9(-4.6;-0.9)	-3.7 (-5.1;-3.7)	1.9 (0.25;6)	-4.2 (-13.1;3)	4(-6.3;29)	-8.4(-14.8,-0.8)	-6.1 (-11.6;1.9)	-4.8(-13.1;-1.8)
Proportion <10%	64.2	60.9	41.7	75.0	79.2	86.4%	87.0	78.9	91.7	84.2	83.3	70.8	100.0	79.2	53.1	37.5	58.3	58.3	58.3
Proportion between 10-20%	22.1	39.1	8.3	25.0	16.7	9.1%	4.3	15.8	8.3	8.4	4.2	8.3	0.0	16.7	26.0	16.7	20.8	29.2	37.5
Proportion between 20-30%	4.2	0.0	12.5	0.0	4.2	1.5%	0.0	5.3	0.0	2.1	0.0	4.2	0.0	4.2	9.4	20.8	4.2	8.3	4.2
Proportion >30%	9.5	0.0	37.5	0.0	0.0	3.0%	8.7	0.0	0.0	5.3	8.3	16.7	0.0	0.0	11.5	25.0	16.7	4.2	0.0

Dilution errors

The median deviations from intended dilution volume for all drugs were low. Adrenaline (4kg child) had the highest number of percentage errors with a deviation of >30%. This was due to the fact that one participant did not double dilute the adrenaline as he had intended to for both dosages.

Administration errors

With adrenaline there were volumes administered that deviated by >20% from intended administration volumes in 14 of the 46 doses. Adrenaline administered to the 4kg child, had the highest proportion of errors with 11 of the 24 dosage having percentage errors of >20%; 6 of these with errors >30% (median 4%, IQR -6.3%; 29%). When a 10ml syringe was used to dilute and administer 0.4ml, there were large errors in administration volumes. Of the 8 cases where this was done, all 8 had errors of >20%. In 3 cases these errors were almost 100% deviations. When a smaller syringe (5ml or 2ml) was used to administer medications, fewer administration errors were made. In 26 dosages in which a 10ml syringe was used to withdraw, dilute and administer adrenaline, the average deviation from intended administered dose was 26%, whereas when 5ml/2ml syringe was used to administer medications (22 dosages), the average deviation was 9%. This difference was more drastic in the 4kg child scenario (46% vs. 12.6%).

Time

Overall the median time taken to deliver all drugs was 79 seconds (IQR 59; 100 seconds). Adrenaline (4kg child) (median 94 seconds, IQR 75; 106 seconds) and ketamine (median 92.5 seconds, IQR 67; 106 seconds) took on average the longest

time to prepare and administer. Adrenaline (15kg child) (median 80 seconds, IQR 70; 97) took on average 10 seconds less time, with amiodarone taking the least amount of time (median 47, IQR 41; 65 seconds). Interquartile ranges were comparable for all medications.

Spillage

Adrenaline for the 4kg child had the highest average spillage, with the other drugs having minimal average spillages. The average spillage for all dosages was 0.19ml (see Table 1).

DISCUSSION

Resuscitations are very stressful situations that require healthcare practitioners to respond promptly and work as a team while having little time for discussion. Tasks such as medication preparation and delivery are performed by both nurses and doctors during resuscitations. Current literature reviewing medication errors in resuscitations is limited and has focused mainly on drug dosing errors. Only two studies could be found that measured actual amounts of medications prepared or delivered in resuscitations in an attempt to quantify these errors.

A nursing study, comparing actual volumes of medications prepared to intended volumes, found that 32% of dosages had significant errors, with a mean deviation of 8%. Unfortunately, it is unclear what deviations were considered to constitute medication errors (Table 3a) [7].

Table 3a: *Adapted from Opportunities for performance improvement in relation to medication administration during paediatric stabilization. N Morgan, X Luo, C Fortner, K Frush. Qual Saf Health Care 2006;15:179–183. doi: 10.1136/qshc.2005.017350*

Analysis of deviations of actual vs intended drug volumes withdrawn				
Drug	**No (%) measured incorrectly**	**Mean Deviation (%)**	**Median Deviation (%)**	**Maximum Deviation (%)**
Dextrose (N = 30)	9 (30%)	1.50	0	23.10
Lorazepam (N = 30)	15(50%)	22.40	1.50	146
Fosphenytoin (N = 30)	10(33%)	3.40	0	61.50
Phenobarbitol (N = 30)	9(30%)	4.70	0	60
Ceftriaxone (N = 30)	6(20%)	7.20	0	80
Total (N = 150)	49(32.7%)	8	0	146

Another study, looking at the incidence of medication errors in paediatric simulated resuscitations, assessed the concentration of prepared medications (Table 3b) [10]. This study found that 15.5% (9 of 58 dosages) had deviations of >20% from what was intended. However, it did not look at the events that led to the errors in concentration, nor the administered volume that would determine whether the dosage would be harmful. In these studies, medication delivery was performed mainly by emergency nurses.

Table 3b: *Adapted from "Prospective observational study on the incidence of medication. Errors during simulated resuscitation in a paediatric emergency department. Eran Kozer, Winnie Seto, Zulfikaral Verjee, Chris Parshuram, Sohail Khattak, Gideon Koren, D Anna Jarvis, BMJ, doi:10.1136/bmj.38244.607083.55 (published 28 September 2004)*

Deviation of expected vs actual drug concentrations		
Drug	**No of syringes analyzed**	**No with discrepancy >20%**
Electrolytes	16	0
Glucose	4	0
Anticonvulsants	10	3
Amines	20	3
Atropine	4	2
Others	4	1
Total	58	9

Table 3c: *Adapted from Color-Coded Prefilled Medication Syringes Decrease Time to Delivery and Dosing Error in Simulated Emergency Department Paediatric Resuscitations Maria E. Moreira; Caleb Hernandez; Allen D. Steven; Seth Jones; Margaret Sande; Jason R. Blumen; Emily Hopkins; Katherine Bakes; Jason S. Haukoos. http://dx.doi.org/10.1016/j.annemergmed.2014.12.035*

Variable	Median time(sec)	95% CI
All medications	47	40-53
First dose of atropine or epinephrine	69	57-77
Rapid sequence intubation medications:		
1		
2	106	90-115
3	172	156-212
4	242	Undefined

Our study identified a number of errors that occurred in the preparation and administration process. These were seen for both junior and senior doctors. Most of the errors occurred during the withdrawal of drug phase, as well as the administration of medication phase. Dilution of all medications occurred with the least errors. This poses a big concern as deviations from expected volumes during drug withdrawal could lead to large deviations in end concentrations. These deviations from intended drug volumes were highest for the ketamine group in which most participants used 10 ml syringes to draw up small volumes of ketamine. In the withdrawal of adrenaline, the impact of using a 10 ml syringe to withdraw medications was minimal as the entire content of the ampoule was withdrawn, in most cases without participants checking how much was actually withdrawn. This in itself is a practice that should be avoided. With amiodarone, mainly 2ml and 5ml syringes were used to draw up the medication and the smallest

number of errors were seen. The highest deviations from expected administration volumes occurred with adrenaline in the infant scenario where in numerous scenarios 10ml syringes were used to administer volumes of 0.4ml which lead to very large errors. Diluent volumes were usually large and therefore the use of larger syringes was appropriate.

These findings are consistent with studies done outside of the emergency department where manipulations of medications, such as diluting it down, has been shown to often lead to errors [13]. In addition, numerous studies have highlighted the high incidence of errors that occur during the preparation of small volumes of medications [14-17]. Research evaluating the dilution of adult vials to administer a paediatric dose has resulted in errors of between 10 and 100 fold [18,19].

Syringe accuracy is affected by various factors including the brand, the syringe size as well as the type fluid being measured. Manufacturers have been urged to assist with some of the shortcomings of paediatric medication delivery [20]. The European Union's Paediatric Regulation has also recognized the need for paediatric medications which would translate into appropriately sized vials that are easier to prepare and administer [21].

An additional consideration that may contribute to overdosing is the dead space within a syringe. This is the volume that remains in the hub of the syringe and needle after the plunger is compressed fully (varies from 0.07 to 0.20 ml depending on syringe size) [22]. This could lead to harm in drugs with a with a narrow therapeutic index [23,24].

There are a number of actions that have been found to decrease the accuracy of prepared medications. These include using the same syringe to measure medication and diluent; not using the correct syringe size for the volume being measured; and not checking measured volumes especially after withdrawing the full content of a vial [25]. Syringe selection is a very important process. A larger volume syringe will be less accurate than a smaller volume syringe for measuring small volumes. For example, when measuring 1ml, it would be more accurate to use a 1ml syringe than it is using a 5ml syringe. In addition, each volume of drug and diluent should be measured separately using an appropriate sized syringe. Transferring the volume of one syringe to the other by introducing the needle of one syringe into the tip of the other, is a practice that should be avoided. Volume transfer devices should rather be used to perform these tasks [12]. Calmer environments for preparation have also been shown to be a factor that improves precision [26].

Providing adequate training and supervision of healthcare professionals involved in medicine preparation is a crucial step to reduce errors. However, there are no international guidelines that govern medication preparation in a clinical environment [27]. This is a major concern as most emergency medication practitioners and nurses do not have this basic training. The errors in the preparation and administration found during resuscitations in this study, as well as the those in other studies, suggest that this a major concern that could have catastrophic consequences. More work is thus required to determine how best to prepare and administer medications to children during resuscitation situations, especially when small volumes are required [28] .

The time taken to administer medications was another concern. In some cases, medication preparation took so long that it had to be administered in the following cycle of CPR. This was the case with adrenaline which required more complex cognitive steps, which meant that participants spent time working out how best to dilute the medications. The average time taken for delivery of all medications (79 seconds) in this study is comparable with the times taken to deliver emergency medications using conventional syringes (69 seconds for first dose of atropine and ephedrine) in a study by Moreira et al (2015)(Table 3c). The latter study compared the times taken using conventional syringes vs colour coded prefilled syringes [4]. Given the potential for error with rushing medication delivery, caution should be exercised with prioritising rapid preparation of medications rather than accurate preparation and administration.

Limitations

The calculation of volume from the weight of the fluid assumes that the density of Normal Saline will be 1.005 g/ml. Given that the temperature of the environment and fluids cannot be kept constant, this may account for very slight inaccuracies in the total volume calculated. The spillage in the study was a significant limitation as it was not always possible to determine whether this spillage occurred during withdrawal of drugs/diluents phase, during the administration phase or through environmental loss. Because the differences in vial weights were used to calculate drug/diluents volumes withdrawn this would mean that the spillage data could be included in any of these values, thus these readings could be overestimated. The average spillage for all 96 dosages was 0.2ml which was minimal and in most cases was observed to be during

the withdrawal of diluents phase which had the fewest number of percentage errors >20%. It was not always possible to observe spillage using video recordings, in cases where this was observed a large volume of fluid may have been discarded to measure out a correct volume. The effects of different medications on the error in preparation and administration were not considered, for example, the bubbling of amiodarone during preparation could potentially further increase the magnitude of the errors.

Simulated resuscitation using manikins do not exactly represent an emergency environment, however significant effort was made to ensure that the experience was as realistic as possible. Participants may have identified the purpose of the study and may have tried harder to perform their best (Hawthorn effect). Thus, the rate of medication errors identified could be lower than in a real life situation and the time taken to deliver medications could be overestimated.

Participants were limited to only 2ml, 5ml and 10ml syringes. These were consistent with the sizes that were generally available to staff during resuscitations in our setting. This could have either improved accuracy or the time taken to prepare medications or worsened the results.

Finally, we did not look at how prefilled syringes may have reduced the observed errors- this was beyond the scope of this study.

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APPENDICES

Appendix 1 – Ethics Clearance

R14/49 Dr Sashen Murugan

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M170221

NAME: (Principal Investigator)	Dr Sashen Murugan
DEPARTMENT:	Emergency Medicine Helen Joseph Hospital, Emergency Department
PROJECT TITLE:	Assessing for Preparation and Administartion Errors: A Prospective Observation Study of Paediatric Resuscitation Simulations
DATE CONSIDERED:	24/02/2017
DECISION:	Approved unconditionally
CONDITIONS:	
SUPERVISOR:	Prof Mike Wells and Dr Pano Parris
APPROVED BY:	Professor P. Cleaton-Jones, Chairperson, HREC (Medical)
DATE OF APPROVAL:	19/06/2017

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Research Office Secretary in Room 10004,10th floor, Senate House/3rd floor, Phillip Tobias Building, Parktown, University of the Witwatersrand. I/We fully understand the conditions under which I am/we are authorised to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated, from the research protocol as approved, I/we undertake to resubmit to the Committee. **I agree to submit a yearly progress report**. The date for annual re-certification will be one year after the date of convened meeting where the study was initially reviewed. in this case, the study was initially review February and will therefore be due in the month of February each year. Unreported changes to the application may invalidate the clearance given by the HREC (Medical).

Principal Investigator Signature Date