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ORIGINAL ARTICLE

Analysis of medication prescribing errors in critically ill children

Corina Glanzmann[1] · Bernhard Frey[2] · Christoph R. Meier[3] · Priska Vonbach[1]

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Abstract Medication prescribing errors (MPE) can result in serious consequences for patients. In order to reduce errors, we need to know more about the frequency, the type and the severity of such errors. We therefore performed a prospective observational study to determine the number and type of medication prescribing errors in critically ill children in a paediatric intensive care unit (PICU). Prescribing errors were prospectively identified by a clinical pharmacist. A total of 1129 medication orders were analysed. There were 151 prescribing errors, giving an overall error rate of 14 % (95 % CI 11 to 16). The medication groups with the highest proportion of MPEs were antihypertensives, antimycotics and drugs for nasal preparation with error rates of each 50 %, followed by antiasthmatic drugs (25 %), antibiotics (15 %) and analgesics (14 %). One hundred four errors (70 %) were classified as MPEs which required interventions and/or resulted in patient harm equivalent to 9 % of all medication orders (95 % CI 6.5 to 14.4). Forty-five MPEs (30 %) did not result in patient harm.

Conclusion: With a view to reduce MPEs and to improve patient safety, our data may help to prevent errors before they occur.

What is Known:

- *Prescribing errors may be the most frequent medication errors.*
- *In paediatric populations, the incidence of prescribing errors is higher than in adults.*

What is New:

- *Several risk factors for medication prescribing errors, such as medication groups, long PICU stay, and mechanical ventilation could be presented.*
- *Analysing the combination of the most frequent prescribing errors and the severity of these errors.*

Keywords Children · Intensive care · Clinical pharmacist · Prescribing error · Error rates · Classification

Abbreviations

ANZPIC	Australian and New Zealand Paediatric Intensive Care Registry
ARF	Acute renal failure
ALAT	Alanine-aminotransferase
ASAT	Aspartate-aminotransferase
ATC	Anatomical therapeutical chemical classification
CI	Confidence interval
CPOE	Computerized physician order entry
CRP	C-reactive protein
die	Day
f	Female
g	Gram
GGT	Gamma-glutamyl-transferase

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✉ Corina Glanzmann
pharma@kispi.uzh.ch

[1] Hospital Pharmacy, University Children's Hospital Zürich, Steinwiesstrasse 75, 8032 Zürich, Switzerland

[2] Department of Intensive Care and Neonatology, University Children's Hospital Zürich, Steinwiesstrasse 75, 8032 Zürich, Switzerland

[3] Hospital Pharmacy, University Hospital Basel, Spitalstrasse 26, 4031 Basel, Switzerland

Iv or i.v.	Intravenous (way of drug application)
L	Litre
m	Male
MDSi	Minimal data set intensive care
mg	Milligram
mcg	Microgram
mcmol	Micromol
mmol	Millimol
MODS	Multiple organ dysfunction syndrome
MPE	Medication prescribing error
NCCMERP	National Coordinating Council for Medication Error Reporting and Prevention
PCNE	Pharmaceutical Care Network Europe
PICU	Paediatric intensive care unit
PIM	Paediatric Index of Mortality Score

Introduction

In the current health care system, especially in neonatal and paediatric intensive care, medication errors are possibly an important source of morbidity [13, 18, 21, 32, 33, 40, 41] and efforts for improvement are paramount. Medication errors range from those with very serious consequences to those that have little impact on the patient. It has thus been suggested that the severity as well as the prevalence of errors should be taken into account [2]. Assessing the severity of errors increases the quality of information regarding the clinical relevance.

Children are a challenging group of patients because most drug dosages in paediatric medication are calculated individually, based on the patient's age, weight or body surface area. Furthermore, the frequency of unlicensed and off label drug prescriptions is about 50 to 70 % depending on the method of analysis and the clinical setting [8]. This may increase the potential for medication errors. Limited evidence suggests that the prevalence of medication errors and corresponding harm may be higher in children than in adults (1.1 vs 0.35 %, $P<0.001$) [18]. Especially, patients admitted to an intensive care unit (ICU) are at high risk for medication errors due to the critical nature of their illnesses, polypharmacy and the use of high-risk drugs [19].

A review estimates that 5 to 27 % of medication orders for children contain an error somewhere along prescribing, dispensing and administering. The review also estimates that there are 100 to 400 prescribing errors per 1000 patients [26]. There have been two studies investigating paediatric prescribing errors in the UK, one showing an error rate of 5.3 % and the other not presenting error rates [5, 27]. Other studies in the USA found that prescribing errors occur in 0.4 to 1.9 % of all written medication orders [21, 26, 27] and cause harm in about 1 % of all inpatients [5]. Ghaleb et al. [16] carried out a prospective review of drug charts by pharmacists and researchers across five London hospitals over a 2-week period. This study found a prescribing error rate of 13 %, which is higher than in previous studies.

However, a major problem with interpreting quantitative prescribing error studies is that the definition of an error used by the researchers is often ambiguous or not given at all. Often, studies include all medication errors and do not distinguish clearly enough between prescribing errors and other types of errors [16].

The definition used in a study will impact directly on its result, and research in this area is therefore particularly hard to interpret [14].

In addition, the different methods of detecting prescribing errors make it difficult to compare studies. Higher rates of prescribing errors were detected by retrospective reviews compared to prospective assessments. Spontaneous reporting and the use of retrospective trigger tools were not accurate to detect prescribing errors [14].

To assess the epidemiology of MPEs in critically ill children may help to reduce serious errors in the use of prescribed drugs. Our goals were (1) to determine the rates of MPEs, (2) to analyse the major types of errors and the drugs most commonly involved, and (3) to assess the severity of these errors.

Methods

Setting, study population and data source

We performed a prospective observational study to determine the number and type of medication prescribing errors in critically ill children in the paediatric intensive care unit (PICU) at the Children's Hospital in Zürich during a 10 months period in 2010. Prescribing errors were prospectively identified by one of three clinical pharmacists as part of their routine prescription monitoring. The pharmacist reviewed every order before the ward round starts. Only medication orders on Monday, Wednesday and Friday were included in this analysis, because only on these days a clinical pharmacist participated on the ward rounds. Ward rounds are held together with a senior physician, two residents and two nurses. The pharmacist told the medical and nursing PICU team which prescribing errors occurred in order to prevent harm to the patient.

The PICU is divided into a general PICU (9 beds) and a cardiac PICU (9 beds). The whole range of neonatal (including preterms), paediatric, surgical and cardiac surgical patients is admitted, excluding liver transplant patients. All up-to-date procedures are offered, including high-frequency oscillatory ventilation, inhaled nitric oxide (NO), renal replacement therapy (peritoneal dialysis and haemofiltration) and extracorporeal membrane oxygenation (ECMO). About 25 % of patients are neonates, mainly with cardiac and/or surgical pathologies. The study has been approved by the local Ethics Committee.

All patients who were admitted to the general PICU between April and December 2010 were eligible to be included into the study. Each readmission after 24 h outside PICU was considered a new and separate case. Demographic parameters (sex, age and weight) and factors relating to severity of illness (length of PICU stay, mechanical ventilation, Paediatric Index of Mortality 2 (PIM2) [36]) were surveyed by means of the minimal data set (MDSi) of the Swiss Society of Intensive care [43]. Information on drugs prescribed during PICU stay (according to the anatomical therapeutical chemical (ATC) classification), laboratory parameters (serum creatinine, albumin, aspartate-aminotransferase (ASAT), alanine-aminotransferase (ALAT), c-reactive protein (CRP)), main diagnosis (according to the Australian and New Zealand Paediatric Intensive Care Registry (ANZPIC) Diagnostic Codes [35]), were obtained from the electronic patient records or the order sheets.

Age was categorized into five different age groups: neonates (0–4 weeks), infants (≥1–12 months), toddlers (≥1–4 years), children (≥5–11 years), or adolescents (≥12 years).

The main diagnoses were categorized into the following groups: airway, cardiovascular, gastrointestinal, infection, injury, miscellaneous, neurological, post procedural or renal [35].

Paediatric Index of Mortality (PIM) Score was categorized into three different strata related to the expected risk of mortality in percentages: category 1 (0–0.99 %), category 2 (1.0–9.99 %) or category 3 (10–100 %) [39].

Number of medications was defined as the number of different drugs that a study subject received during the study period except the drugs kept in reserve.

Drugs were ordered by means of an excel order form without drug-drug interaction information. This order form was created by a resident of the PICU. Residents wrote prescriptions on a structured form using a laptop computer at bedside. There were some calculation aids, such as calculating the whole dose from the dose per kilogram body weight. For the preparation of continuous drips, standardized tables were used, so that the residents only needed to order the amount of the medication per time (e.g. adrenaline: 0.1 mcg/kg/min). All medication was prepared by nurses. Regular orders, valid from 2 to 2 pm of the next day, were written on morning rounds and printed out. Additional orders, if required later than 2 pm, were written by hand on the back of the order form.

Medication prescribing error definition

For the purpose of this study, a clinically meaningful medication prescribing error (MPE) was defined as a prescribing decision or prescribing writing process that resulted in an unintentional, significant reduction in the probability of treatment being timely and effective or increase in risk of harm, when compared with generally accepted practice [3].

Identification and classification of medication prescribing errors

MPEs were classified according to an adapted Pharmaceutical Care Network Europe (PCNE) classification [30]. Only six of the eight primary domains of PCNE for causes of MPEs were used for the classification: drug selection (the cause of the MPE can be related to the selection of the drug, i.e. no indication for drug, inappropriate combination of drugs (interactions), indication for drug treatment not noticed and too many drugs prescribed for indication), drug formulation (the cause of the MPE is related to the selection of the drug formulation), dose selection (the cause of the MPE can be related to the selection of the dosage schedule), treatment duration (the cause of the MPE is related to the duration of therapy), drug use process (the cause of the MPE can be related on the way the patient gets the drug administered), or other problems. The domain ‘missing information’ (the cause of the MPE can be related to omitting information) was added. Additionally, sub domains were formed for each main domain which can be seen explanatory for the principal domains. The other primary domains such as domains for problems and domains for interventions were not taken into account because we only wanted to classify prescribing errors.

Classification of the dosage

For calculation and verification of the correct drug dose, the dosage booklet published by the Children’s Hospital Zürich in 2009 was used [9]. This booklet contains dosages for regulatory approved drugs, as well as information on drugs which are not approved, but for which evidence or at least eminence-based paediatric dosages are available. If the drug dose was not in the range given in the booklet, the dose was considered to be wrong.

Classification of drug-drug interactions

Drug-drug interactions occur when the effect of one drug is changed by the presence of another drug.

All medication orders were screened for drug-drug interactions using the interaction screening programme Pharmavista [11]. The programme classifies the severities of drug-drug interactions into five categories: major, moderate, minor, insignificant or of unidentified source. In this study, only the categories major, moderate and minor were taken into account for an inappropriate drug selection/drug dose.

Categorisation of medication prescribing errors by severity

A classification according to the National Coordinating Council for Medication Error Reporting and Prevention

(NCCMERP) was used [38] (Table 1). Each MPE was independently scored for error severity by a clinical pharmacist and by a senior intensive care physician. Any disagreements were resolved by a senior clinical pharmacist.

Statistical analysis

Demographic variables were summarized using descriptive statistics. Differences between patients with MPEs and patients without MPEs were analysed using Fishers exact test for categorical variables and Wilcoxon test (also known as Mann–Whitney *U* test) for continuous variables because assumptions of normality could not always be satisfied. Continuous variables were expressed as median; categorical variables were expressed as proportions (%).

The error rate was calculated as the percentage of errors relative to total drug orders with 95 % confidence intervals (CI).

In a second step, we classified the most frequently administered drugs into nine different groups (drugs for cardiac stimulation, diuretics, antiasthmatics, antibiotics, antiepileptics, antimycotics, analgesics, antihypertensives or nasal preparations). We then calculated proportions of errors attributable to given medication groups with 95 % CI.

All of the data analysis were conducted using the software programme SAS, version 9.3 (SAS Institute, Inc, Cary, NC).

Results

Number and rates of medication prescribing errors

A total of 153 patients and 1129 medication orders were analysed throughout the study period. There were 151 prescribing errors, giving an overall error rate of 14 % (95 % CI 11 to 16). Medication orders from 65 patients contained one or more MPEs. Dose selection errors were the most common type of MPEs with an error rate of 6.6 % (95 % CI 5.3 to 8.3) followed by drug selection errors with an error rate of 2.1 % (95 % CI 1.3 to 3.0). A list of the most frequent MPEs and their associated error rates is given in Table 2.

Drug categories associated with errors

The involvement of medication groups according to the ATC in MPEs is shown in Table 3. The medication groups with the highest proportion of MPEs were antihypertensives, antimycotics and drugs for nasal preparation with error rates of 50 % each, followed by antiasthmatic drugs (25 %), antibiotics (15 %) and analgesics (14 %).

Severity of medication prescribing errors

There was a high grade of accordance (96 %) between the senior physician and the clinical pharmacist concerning the classification of the severity of the MPEs. Only six errors had to be solved by the senior pharmacist. The distribution of the severity ratings for MPEs showed that 106 errors (70 %) were classified as MPEs which required interventions and/or resulted in patient harm (severity category D to H) equivalent to 9 % of all medication orders (95 % CI 6.5 to 14.4). Forty-five MPEs (30 %) did not result in patient harm (severity categories A, B and C). The detailed distribution of the severity ratings is shown in Table 4.

Demographic differences in patients with or without medication prescribing errors

In general, demographic characteristics differed little between patients with or without MPEs. In particular, there were no differences regarding age, gender, weight (except for neonates) and main diagnoses (Table 5).

Table 1 Severity of medication prescribing errors

Major divisions	Subcategory	Description
Error, no harm	Category A	Circumstances that have the capacity to cause error
	Category B	Error did not reach the patient because it was intercepted before or during administration process
	Category C	Error reached the patient but did not cause patient harm
Error, potential preventable ADE	Category D	Error reached the patient and required monitoring to confirm that it resulted in no harm to the patient and/or required intervention to preclude harm
Error, preventable ADE	Category E	Error may have contributed to or result in temporary harm to the patient and required intervention
	Category F	Error may have contributed to or result in temporary harm to the patient and required initial or prolonged hospitalization
	Category G	Error may have contributed to or resulted in permanent harm
	Category H	Error required intervention necessary to sustain life

Classification according to the National Coordinating Council for Medication Error Reporting and Prevention (NCCMERP) [23]

Table 2 Number and error rates of MPEs

Categories	Number of MPEs (*N* (%))	Error rates (%)	95 % CI for error rates
All	151 (100)	14	11; 16
Dose selection	75 (50)	6.6	5.3; 8.3
Dose too high	22 (15)	1.9	1.2; 2.9
Dose too low	17 (11)	1.5	0.9; 2.4
Drug formulation	7 (4.6)	0.6	0.2; 1.3
Drug selection	23 (15)	2.1	1.3; 3.0
Pharmacodynamic interaction	9 (6.0)	0.8	0.4; 1.5
Pharmacokinetic interaction	11 (7.3)	1.0	0.5; 1.7
Missing information	21 (14)	1.9	1.2; 2.8
Missing drug formulation	16 (11)	1.4	0.8; 2.3
Other problems	18 (12)	1.6	0.9; 2.5
Treatment duration	0	0	0; 0.3

However, as reported in Table 6, the MPE-patient group was different from the group without MPEs with regard to the severity of illness described by the median length of PICU stay (7 vs 3 days), the median length of mechanical ventilation (31 vs 2.7 h) and the median number of prescribed drugs (9 vs 5 drugs).

Discussion

The findings of our study support the notion that MPEs occur frequently with an overall error rate of 14 %, a proportion which is higher than the one reported in adults of a tertiary care teaching hospital [25]. Much has been written on the importance of medication errors in paediatrics and in particular on prescribing errors [7, 15, 29, 34]. The error rate of 14 % in the current study population is comparable to other published data [4, 31], even though a direct comparison of error rates across various studies is difficult due to variations in the definitions used and in the methodology. Davis [6] recently pointed out that reaching a generally accepted definition is difficult. The errors reported in our study were all identified by a pharmacist. Other studies have used reviews based on medical notes and have focused on those errors that resulted in patient harm [22, 23, 34]. We do not know whether the errors that result in patient harm differ substantially from those that are identified before harm can result.

The main prescription error in our study was wrong dosing (overdosing or underdosing), with an error rate of 50 % of all prescribing errors. This is in line with findings of most previous studies [7, 13, 24, 42]. The frequent need for dose calculations required in paediatrics for weight based dosing is most likely an important factor contributing to the high rates of dosing errors.

Other authors have found that incomplete medication orders are the most frequent prescribing error [16]. In our study, missing information (error rate 14 %) was located on third place. The reason for this discrepancy could be that in the other studies, data were generally gathered on manual prescribing systems, whereas we gathered data from a 'half-electronic' order form.

The second most common MPE in our study was the wrong selection of the drug (error rate 15 %) potentially resulting in a drug-drug interaction. Risk factors for this may

Table 3 Medication groups associated with MPE

Medication groups	Number of drug orders	Number of MPEs	Percentage of errors[a]	95 % CI for error rates
Analgesics	301	43	14	11; 19
Antiasthmatics	20	5	25	8.7; 49
Antibiotics	130	19	15	9.0; 22
Antiepileptics	111	18	16.2	9.9; 24
Antihypertensives	14	7	50	23; 77
Antimycotics	6	3	50	12; 88
Diuretics	39	6	15	5.9; 31
Drugs for cardiac stimulation	28	3	11	2.3; 28
Drugs for nasal preparation	12	6	50	21; 79

[a] Proportion of errors attributable to a given medication group

Table 4 Classification of MPEs regarding severity

Major divisions	Subcategory	Number of MPEs (*N* (%))	Error rates (%)	95 % CI for error rates
Error, no harm	Category A	8 (5)	0.5	0.2; 1.2
	Category B	19 (12)	1.4	0.8; 2.3
	Category C	20 (13)	1.5	0.8; 2.4
Error, potential preventable ADE	Category D	81 (54)	7.0	5.6; 8.6
Error, preventable ADE	Category E	19 (13)	1.5	0.9; 2.4
	Category F	1 (1)	0.0	0.0; 2.5
	Category G	2 (1)	0.0	0.0; 0.6
	Category H	1 (1)	0.0	0.0; 0.5

include the use of multiple drug therapies in critically ill children with multisystem disorders, making drug-drug and also drug-patient interactions more likely.

All these errors were more likely to occur among children with longer stay and greater medication exposure than for children with shorter stay and/or requiring fewer drugs. The association between length of stay and MPE may be explained by two different scenarios: (1) the longer the PICU stay, the greater risk of a prescribing error or (2) due to a MPE, the PICU stay could be prolonged. It also appears that these errors could be a consequence of disease severity where the cases were more complicated and the prescriptions more complex.

Table 5 Characteristics of patients with and without medication prescribing errors

Categories	All *N*=153	Patients with MPE *N*=65	Patients without MPE *N*=88	*P* value
Age (in categories)				0.499
Neonates	47 (31 %)	17 (26 %)	30 (34 %)	
Infants	31 (20 %)	16 (25 %)	15 (17 %)	
Toddlers	25 (16 %)	9 (14 %)	16 (18 %)	
Children	21 (14 %)	8 (12 %)	13 (15 %)	
Adolescents	29 (19 %)	15 (23 %)	14 (16 %)	
Sex				0.311
Male	97 (63 %)	38 (58 %)	59 (67 %)	
Female	56 (37 %)	27 (42 %)	29 (33 %)	
Weight	Kg	kg	kg	*P* value
All	9.5 (0.8, 84)[a]	9.5 (0.8, 84)[a]	9.2 (1.3, 72)[a]	0.602
Neonates	3.0 (0.8, 8.4)[a]	2.5 (0.8, 4.2)[a]	3.1 (1.3, 8.4)[a]	0.050
Infants	6.4 (1.3, 10)[a]	6.4 (1.3, 9.5)[a]	6.4 (2.8, 10)[a]	0.984
Toddlers	14 (10, 30)[a]	14 (11, 30)[a]	13 (10, 17)[a]	0.649
Children	23 (16, 41)[a]	26 (16, 41)[a]	22 (16, 25)[a]	0.405
Adolescents	46 (14, 84)[a]	49 (18, 84)[a]	39 (14, 72)[a]	0.570
Main diagnosis				0.560
Airway	32 (21 %)	14 (22 %)	18 (21 %)	
Cardiovascular	8 (5.2 %)	5 (7.7 %)	3 (3.4 %)	
Gastrointestinal	14 (9.2 %)	7 (11 %)	7 (8.0 %)	
Infection	2 (1.3 %)	0 (0 %)	2 (2.3 %)	
Miscellaneous	28 (18 %)	15 (23 %)	13 (15 %)	
Missings	2 (1.3 %)	1 (1.5 %)	1 (1.1 %)	
Neurological	21 (14 %)	7 (11 %)	14 (16 %)	
Post procedurals	29 (19 %)	9 (14 %)	20 (23 %)	
Renal	5 (3.3 %)	3 (4.6 %)	2 (2.3 %)	

N number of patients

[a] Median with range

Table 6 Severity of illness parameters of patients with and without medication prescribing errors

Categories	All *N*=153	Patients with MPE *N*=65	Patients without MPE *N*=88	*P* value
Mechanical ventilation (Yes)	91 (60 %)	42 (65 %)	49 (56 %)	0.318
Length of mechanical ventilation (hours)	6.5 (0, 2762)[a]	31 (0, 2762)[a]	2.7 (0, 766)[a]	0.003
PIM2 score				0.055
Category 1 (0–0.99 %)	57 (37 %)	25 (38 %)	32 (36 %)	
Category 2 (1–9.99 %)	80 (52 %)	29 (45 %)	51 (58 %)	
Category 3 (10–100 %)	16 (11 %)	11 (17 %)	5 (6 %)	
Length of PICU stay (days)	4 (1, 116)[a]	7 (2, 116)[a]	3 (1, 20)[a]	<0.001
Number of medications	6 (1, 29)[a]	9 (1, 29)[a]	5 (1, 15)[a]	<0.001

N number of patients

[a] Median and range

MPEs occurred across many different main diagnoses and were associated with a wide range of drugs. In our study, antihypertensives, antimycotics and drugs for nasal preparation (e.g. Oxymetazolin Nasal Sprays) were most commonly involved in MPEs with an error rate of 50 % each. These findings are not consistent with other published paediatric studies, where antibiotics, steroids, anticoagulants and hormones were the drugs most commonly related to MPEs [1, 17, 20, 21, 25]. These differences suggest that MPEs found in a PICU cannot be generalized to other children wards, and that different definitions of MPEs result in differing rates of errors. Additionally, drugs less frequently prescribed by physicians such as antimycotics (only 6 orders out of 1129 medication orders), drugs for nasal preparation (12 of 1129) and antihypertensives (14 of 1129) are less known and therefore more prone to errors. Another reason for the high error rate of antihypertensives may be related to the fact that this medication group is subjected to frequent changes in dosing, which makes the prescribing process even more difficult. Overall, these drug categories should be emphasized in the ongoing education of the entire team.

In our study, analgesics were the medication group with the greatest number of MPEs (43 errors, 14 %). These were the most frequently prescribed drugs in our PICU, and it is therefore not surprising that they accounted for more errors than other groups.

Antibiotics were the second most commonly prescribed medication group in our study and therefore also often involved in MPEs (error rate 15 %). Nevertheless, error rates in other studies were often higher than 15 %. The percentages in previous studies were as follows: Folli et al. 36 % [13]; Struck et al. 34 % [37]; Lesar et al. 40 % [25] and Ross et al. 44 % [33]. However, these studies cannot be directly compared to our study because they focussed on medication errors or interventions rather than on MPEs. Paediatric patients are important targets for efforts aiming at reducing unnecessary antibiotic use [10, 37].

With regard to error severity, our results showed that harmful or potentially harmful errors accounted for 66 % of all MPEs. Although a direct comparison with other studies is hampered by differences between clinical settings, study designs and outcome definitions, we found studies which showed a similar proportion of harmful or potentially harmful errors [19, 28]. Other authors have found lower percentages, ranging from 17 to 36 % [12, 13]. The estimation of severity of MPEs in our study was sometimes difficult. This is primarily because such classifications are rarely available in the literature. Therefore, the determination of severity was somewhat subjective. None of the studies mentioned any harmful effects on the patients, probably because the errors were corrected prior to administration.

Limitations

This study has several limitations. First, as a single-centre study, the findings reflect the situation at only one specific PICU, which may reduce the generalizability of our findings to other clinical settings. Second, the errors reported here were all identified and classified by a clinical pharmacist who gave a feedback to the physician during the round which could introduce a bias into the study. Clinical pharmacists routinely analysed drug charts only on Monday, Wednesday and Friday, and we cannot exclude the possibility of undetected MPEs, hence, underestimating the incidence of MPEs per patient. However, this would not affect the incidence of MPEs per medication orders which we described in our study. Furthermore, we did not test for interobserver reliability between the pharmacists, but all were experienced clinical pharmacists and followed the same guidelines. Nevertheless, further work is needed to establish the reliability of the

identification and documentation of prescribing errors by pharmacists. Third, most of the prescribers in our study were residents. It is unknown whether resident prescribing patterns are different from non-resident prescribers. Forth, we focused on incidence and characteristics of MPE's as a basis for the introduction of preventive measures. In future studies, the mechanisms leading to MPE's should be analysed, such as human factors, sources for drug choice and dosing and the interface between prescriber and prescription.

Conclusion

Our analysis of MPEs revealed that prescribing errors occurred in 14 % of all prescriptions of this PICU. The most frequent errors were wrong dose selection (50 %), wrong drug selection (15 %) and missing information (14 %). By evaluating the types of MPEs and by analysing patient characteristics and medication groups most commonly involved, we were able to identify risk factors for MPEs. At high risk for MPEs were children who received medication groups such as antihypertensives, antimycotics, drugs for nasal preparation, antiasthmatics, antibiotics and analgesics. Long PICU stay and the need for long mechanical ventilation were additional risk factors.

With a view to reduce MPEs and to improve patient-safety, our data may help to prevent errors before they occur. In view of the importance of dosing errors, it seems to be necessary to strengthen the presence of clinical pharmacists as a key element in preventing prescribing errors and reducing patient harm. Even in settings with less resources, a clinical pharmacist can play an important role in enhancing medication safety, particularly in paediatric patients where calculations are often more complex.

Conflict of interest The authors declare no conflicts or financial interest in any product or service mentioned in the manuscript, including grants, equipment, medications, employment, gifts and honoraria.

Author's contributions C. Glanzmann is the main author. B. Frey is the initiator of the study and reviewer. C.R. Meier is the reviewer. P. Vonbach is the initiator of the study and reviewer.

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