ARTICLE

Errors in the Use of Medication Dosage Equations

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Background: Calculation errors in prescribing are a well-recognized problem; however, no systematic studies of actual errors involving calculation or other errors in the use of drug dosage equations are available.

Objective: To characterize the nature and potential adverse consequences of actual prescribing errors involving dosage equations.

Design: Analysis of the characteristics of 200 consecutive prescribing errors with potentially adverse outcomes involving dosage equations.

Setting: Tertiary care teaching hospital.

Measurements: Potential adverse outcomes, prescribing service, medication class, and the process point at which the error was made.

Results: Errors most commonly involved children (69.5%) and antibiotics (53.5%). Forty-two percent of errors were considered to put the patient at risk for a serious or severe preventable adverse outcome. Errors in decimal point placement, mathematical calculation, or expression of dosage regimen accounted for 59.5% of dosage errors. The dosage equation was wrong in 29.5% of dosage errors.

Conclusions: The use of equations to determine medication dosages presents considerable risk to patients for errant dosing and subsequent adverse events or therapeutic failure. Errors may occur in any component of a dosage equation. Health care organizations should implement procedures to reduce the risk for errors resulting from the use of dosage equations.

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Editor's Note: Ironically, while several medical schools are currently debating whether to require calculus as a prerequisite for entrance, this study documents that physicians are deficient in 1 of the basic 3 Rs of grade school: "Rithmetic." (We also can't spell.)
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ERRORS IN the prescribing of medications are the most common cause of preventable adverse drug events.[1] Errors in the use of dosage equations account for more than 15% of all medication prescribing errors, with significant potential for producing adverse effects.[2] Children are at particular risk for this type of error, as the broad range of patient age and size requires dosage individualization, most often using dosage equations. The problem of errors in the calculation of medication dosages has been previously reported.[3-15] Most systematic studies of the problem have evaluated the performance of clinicians on standardized tests of calculation skills.[3-6] The clinical significance of adverse outcomes resulting from errors in the use of dosage equations has been primarily described in isolated case reports.[7,8,16] The objective of this study was to characterize the nature of prescribing errors involving dosage equations that were detected and averted in a teaching hospital.

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RESULTS

Two hundred medication prescribing errors involving the use of dosage equations were detected during the 13 months from April 1, 1995, through May 31, 1996. Errors most commonly involved pediatric services (69.5%), compared with adult services (30.5%). Of the 200 errors, 107 (53.5%) resulted in the prescribing of an overdose, while 93 (46.5%) resulted in underdoses. Errors involving children resulted in overdose 56.1% of the time and underdose 43.9% of the time and did not differ from the results in adult patients ($P>.55$). Dosage calculation errors most commonly involved antimicrobial agents (53.5%); the class of electrolytes, miner-

SUBJECTS AND METHODS

The study was conducted in a 631-bed tertiary care teaching hospital located in Albany, NY. Medication prescribing error data analyzed were collected from April 1, 1995, to May 31, 1996. Major bed allocations during the study consisted of 53 pediatric beds; 20 nursery beds; 50 neonatal intensive care unit beds; 336 medical, surgical, and gynecology beds; 51 adult intensive care unit beds; 52 psychiatric beds; 20 obstetric beds; and 20 rehabilitation beds. The medical staff consisted of housestaff, fellows, and attending physicians from the associated medical school and physicians from the surrounding community with admitting privileges.

All medication orders written or cosigned by a physician during the study were included. Medication orders were reviewed by staff pharmacists and entered into the pharmacy computer system (HBOC, Orlando, Fla) before dispensing. Patient-specific information routinely available to the reviewing pharmacist included patient date of birth, attending service, admitting diagnosis, reported allergies to medications, body weight (for children), and a complete medication profile for the hospitalization. For patients younger than 12 years, a desired dosage per kilogram of weight or per square meter of body surface area is required to be included on the order sheet by hospital policy. Additional information regarding indication for use is provided for antimicrobial and chemotherapeutic agents, which must be ordered on special sheets. A computerized reporting system enables the centralized staff pharmacists to access patient laboratory results from a computer terminal within the pharmacy. The pharmacy computer system has standard automatic checking capabilities for dosage range, allergies, and drug interactions. Pharmacists routinely used the described information sources and additional patient-specific information obtained as needed from the patient, medical record, nursing staff, physicians, and clinical pharmacists to evaluate all medication orders for appropriateness.

Confirmed medication prescribing errors detected by staff pharmacists during the study were obtained as previously described.[2,17] Following the identification of potentially erroneous medication orders, the pharmacist contacted the prescriber or a cross-covering physician to obtain additional information and to discuss the order. Prescribing problems were defined as medication orders that involved the wrong patient, drug, dosage, dosing frequency, route, or dosage form; provided inappropriate indication for use or inappropriate combinations of drugs; documented allergies to ordered medications; contraindicated therapy; were missing critical information; and had other miscellaneous problems. The medication orders in question were confirmed as written, clarified, changed, or discontinued following the discussion between the pharmacist and physician. Errant orders corrected before review by the pharmacy were not included in the study. All confirmed medication prescribing problems were further reviewed by a clinical pharmacist within 24 hours and the reviewer (T.L.) within 72 hours. Further information was obtained or actions were taken to fully understand the problem and ensure that appropriate drug therapy was provided. For each prescribing error, the following data were collected: patient medical record number, date, time of day, prescribing physician, attending service, medication involved, description of the error, and pertinent patient-specific characteristics or other factors related to the error and pertinent to the assessment of potential patient risk resulting from the error.

The clinical significance of each error was based on the potential of the error to be performed and, if performed as ordered, to result in adverse consequences. These included an increased risk for adverse effects or an inadequate therapeutic response. The potential significance of errant orders was evaluated using a previously described rating scale.[2,17] Prescribing errors were classified as potentially fatal or severe, potentially serious, or potentially significant. Errant orders with a negligible potential to cause an adverse consequence or to be performed were classified as problem order errors. Consistency and agreement of assigning an error severity classification to specific errors has been previously evaluated.[2,17] Only those errors classified as severe, serious, or significant (ie, errors with at least a clear potential to produce an adverse outcome) were included. Two hundred consecutive medication prescribing errors that involved errors in the use of dosage equations detected from April 1, 1995, to May 31, 1996, were analyzed and constitute the database for the study.

Medication prescribing errors involving dosage equations were defined as clinically significant prescribing errors that could be ascribed to the process of using a dosage equation or calculating a dosage. Orders were defined as those orders for which a dosage equation was written on the order sheet or was clearly used as implied by the order and confirmed as used during the discussions between the pharmacist and prescriber. Errant orders in which the error could be attributed to any part of the dosage equation or final calculation (drug, dosage, dosage rate, dosage frequency, or route) were included. Each error in the database was analyzed to determine specific characteristics and classified using predetermined definitions of error types. The classification of errors was developed using review of 100 medication prescribing errors detected before April 1, 1995. The classification of dosage calculation errors used in the study is shown in **Table 1**. For each confirmed prescribing error involving dosage equations, the following data were collected and entered into a commercially available relational database: patient medical record number, date, time of day, attending physician service, medication involved, error description, error type, potential severity, and calculation error type involved. Statistical significance of between-group error rates was determined using χ^2 analysis.

als, and vitamins (8.0%); gastrointestinal tract agents (5.5%); hormonal agents (4.0%); xanthines (4.0%); and nonsteroidal anti-inflammatory agents (3.5%). Other classes of medication individually accounted for 3% or less of the errors (**Table 2**).

The rate of errors involving the use of dosage equations per number of total medication orders written, per admission, and per patient day was greater among children than adults ($P<.001$) (**Table 3**). The rate of error per use of dosage equation was not available, as the total number of medication orders written that involved dosage equations for each service was not determined. Of all 200 errors, 42.0% were rated as having the potential to result in serious to severe or serious adverse out-

Table 1. Types of Prescribing Errors Involving Dosage Equations

Error Type	No. (%) of Errors (n = 200)	No. (%) of Errors in Children (n = 139)	No. (%) of Serious Errors* (n = 84)	No. (%) of Serious Errors in Children* (n = 43)	Resulting Error, No. Overdoses (n = 107)	Resulting Error, No. Underdoses (n = 93)
Errors in calculation or stating of dosage						
Decimal point error in calculated dosage	44 (22.0)	21 (15.1)	29 (34.5)	12 (27.9)	15	29
Calculation error	27 (13.5)	23 (16.5)	9 (10.7)	6 (14.0)	13	14
Desired individual dose divided and ordered for each dose	22 (11.0)	15 (10.8)	12 (14.3)	7 (16.3)	0	22
Total daily dosage ordered to be given each dosing interval	14 (7.0)	9 (6.5)	6 (7.1)	3 (7.0)	14	0
Dosing frequency error in calculated dose	8 (4.0)	5 (3.6)	1 (1.2)	0 (0.0)	6	2
Total daily dosage ordered to be given as a single dose	4 (2.0)	3 (2.2)	0 (0.0)	0 (0.0)	4	0
Total	**119 (59.5)**	**76 (54.7)**	**57 (67.8)**	**28 (65.2)**	**52**	**67**
Errors stated on order						
Dosage amount error in dosage equation	21 (10.5)	15 (10.8)	6 (7.1)	2 (4.6)	12	9
Dosage frequency error in dosage equation	20 (10.0)	19 (13.7)	7 (8.3)	4 (9.3)	13	7
Wrong drug or drug salt in equation	10 (5.0)	10 (7.2)	1 (1.2)	1 (2.3)	10	0
Dose unit error in dosage equation	5 (2.5)	2 (1.4)	2 (2.4)	2 (4.6)	2	3
Decimal point error in dosage equation	3 (1.5)	3 (2.2)	0 (0.0)	0 (0.0)	2	1
Total	**59 (29.5)**	**49 (35.3)**	**16 (19.0)**	**9 (20.8)**	**39**	**20**
Other errors						
Product concentration error	15 (7.5)	8 (5.8)	7 (8.3)	3 (7.0)	10	5
Dose chosen, then calculated	5 (2.5)	5 (3.6)	2 (2.4)	2 (4.6)	4	1
Pound-kilogram error	2 (1.0)	1 (0.7)	2 (2.4)	1 (2.3)	2	0
Total	**22 (11.0)**	**14 (10.1)**	**11 (13.1)**	**6 (13.9)**	**16**	**6**

**Includes errors rated as potentially severe or serious.*

Table 2. Medication Classes Involved in Prescribing Errors Involving Dosage Equations

Medication Class	No. (%) of Errors (N = 200)	No. (%) of Errors in Children (n = 139)	No. (%) of Serious Errors* (n = 84)	No. (%) of Serious Errors* in Children (n = 43)	No. of Overdoses	No. of Underdoses
Antimicrobial	107 (53.5)	77 (55.4)	42 (50.0)	23 (53.5)	52	55
Benzodiazepines	2 (1.0)	2 (1.4)	2 (2.4)	2 (4.6)	1	1
Cardiovascular	6 (3.0)	3 (2.2)	5 (6.0)	2 (4.6)	2	4
Anticoagulant	6 (3.0)	1 (0.7)	4 (4.8)	1 (2.3)	2	4
Antiemetic	2 (1.0)	1 (0.7)	0 (0.0)	0 (0.0)	1	1
Gastrointestinal tract	11 (5.5)	9 (6.5)	1 (1.2)	1 (2.3)	7	4
Hormonal	8 (4.0)	4 (2.9)	5 (6.0)	2 (4.6)	4	4
Electrolyte, mineral, and vitamin	16 (8.0)	10 (7.2)	8 (9.5)	4 (9.3)	12	4
Nonsteroidal anti-inflammatory	7 (3.5)	7 (5.0)	1 (1.2)	1 (2.3)	6	1
Narcotic	4 (2.0)	3 (2.2)	1 (1.2)	0 (0.0)	1	3
Respiratory	5 (2.5)	5 (3.6)	2 (2.4)	2 (4.6)	2	3
Antiepileptic	4 (2.0)	0 (0.0)	3 (3.6)	0 (0.0)	3	1
Diuretic	3 (1.5)	3 (2.2)	1 (1.2)	1 (2.3)	2	1
Xanthine	8 (4.0)	8 (5.8)	1 (1.2)	1 (2.3)	7	1
Antihistamine	2 (1.0)	2 (1.4)	0 (0.0)	0 (0.0)	1	1
Miscellaneous	9 (4.5)	4 (2.9)	8 (9.5)	3 (7.0)	4	5
Total	**200 (100.0)**	**139 (100.1)**	**84 (100.2)**	**43 (99.7)**	**107**	**93**

**Includes errors rated as potentially severe or serious.*

comes, with the remaining errors rated as having potential for at least some moderate but clinically significant adverse patient outcomes. Errors involving children were rated as serious 30.9% of the time, compared with 67.2% of errors involving adults ($P<.01$). However, the rate of serious errors per total orders written, per admission, and per patient day were greater ($P<.001$) for children (Table 3). The frequency of severe or serious errors occurring for each medication class are listed in Table 2.

Mistakes were made in the calculation or the expression of the calculated dosage regimen when the correct dosage equation was used in 59.5% of all errors and 54.7% of errors involving children. Errors in calculation accounted for 16.5% of errors involving children.

Table 3. Services Associated With Prescribing Errors Involving Dosage Equations

Prescribing Service	No. (%) of Errors (N = 200)	No. (%) of Serious Errors* (n = 84)	Errors per 1000 Prescriptions	Serious Errors per 1000 Prescriptions*†	Errors per 100 Admissions	Serious Errors per 100 Admissions	Errors per 100 Patient Days	Serious Errors per 1000 Patient Days*†
Pediatric	139 (69.5)	43 (51.2)	4.94	1.53	3.56	1.34	4.34	1.1
Adult	61 (30.5)	41 (48.8)	0.13	0.09	0.43	0.18	0.26	0.3

*Indicates significant difference between services ($P<.001$).
†Indicates errors rated as potentially severe or serious.

Errors in the placement of the decimal point (10-fold) accounted for 22.0% of all errors and 15.1% of errors involving children. The use of an errant dosage equation resulted in 29.5% of all errors and 35.2% of errors involving children. The most common errors involved the wrong dose or frequency used in the equation. Potentially severe or serious errors most commonly resulted from decimal point errors, underdosing due to dividing a desired individual dose and ordering the partial dose to be given each interval, and calculation errors (Table 1).

COMMENT

In a previous report, calculation and decimal point errors accounted for approximately 15% of all prescribing errors in a tertiary care teaching hospital.[2] Although errors in the use of dosage equations are a well-recognized cause of adverse drug events, little data are available regarding the distribution and characteristics of such errors. Most research regarding dosage regimen calculation has concentrated on the ability to calculate the correct volume of a drug product required to deliver a desired dosage.[3-6] In these studies, physicians and nurses performed poorly on the standardized tests. Such errors in prescribing were detected in this study, but accounted for only 7.5% of all prescribing errors involving dosage calculations. This likely reflects the fact that most medications are prescribed in milligrams rather than as a volume of a product. Indeed, calculating the volume of a product instead of a milligram dosage simply increases the risk for error. This type of error is more likely to occur when a dosage is being prepared than in prescribing. Drug dosages should not be prescribed in terms of volume of medication to be given unless that medication is routinely, and only, given as a volume (eg, lactulose and antacid suspensions). The risk for this type of error occurring during drug preparation is largely eliminated when medications are routinely provided as preprepared unit doses by the pharmacy. When clinicians must prepare and administer doses from nonunit dose containers, the ability to calculate a correct volume of drug product required for a prescribed dosage is extremely important.[4,9,13]

Not surprisingly, errors in the use of dosage equations occurred most commonly in pediatric services. Prescribing medications for children routinely involves the use of dosage equations. As such, the risk to children due to such errors is greater. Calculation errors accounted for almost 70% of all detected medication prescribing errors among children during a previous study.[2] Other differences between pediatric and adult services most likely reflect the difference in type of drugs and patients for whom dosage equations are used. We were not able to determine if frequency of using dosage equations (ie, prescribing for children) resulted in more or less proficiency in the use of dosage equations. However, despite any differences, the risk for an adverse event resulting from an error in the use of a dosage equation is clearly greatest for children.

Complicated dosage regimens and confusion regarding the way dosage calculations are stated or expressed frequently appear to cause the errors. Dosage equations may be variably expressed as a total daily dosage to be divided into a number of multiple daily doses (eg, 100 mg/kg per day in 4 divided doses), a total daily dosage to be divided and given at specific times (eg, 100 mg/kg per day divided every 6 hours), or an individual dose to be given multiple times per day (eg, 25 mg/kg 4 times daily) or at specific times (eg, 25 mg/kg every 6 hours). This variability in equation expression is likely to result in prescriber confusion and error. Interestingly, 29.5% of errors were related to the use of the wrong dosage equation. This suggests that the very nature and expression of dosage regimen equations results in prescriber confusion and dosing errors. In addition, the present experience suggests that the more complicated a dosage regimen is, the more likely errors will occur. The risk for error is of particular concern for chemotherapeutic agents to treat cancer, for which very complicated and atypical dosage regimens are used.[18]

The results of this study suggest that the use of dosing equations is an important risk factor for errant prescribing, particularly among children. Because of the nature of the errors, the drugs involved, and the patient population, medication prescribing errors involving dosage calculations are highly likely to result in patient harm if performed. Health care organizations should institute programs designed to prevent adverse outcomes resulting from prescribing errors involving the use of dosage equations and calculations by implementing initiatives that improve prescriber performance, reduce the need for calculations in prescribing, and provide effective dosage-checking procedures. Dosage checking would best be performed by pharmacists, who perform dosage calculations significantly better than physicians and nurses.[5] However, this needs to be a routine safety measure, not a substitute for ensuring that all prescribers have good dosage calculation skills, which will be required when such redundant safety checks are not available. At the study hospital, all drug orders for children weighing less than 50 kg require the inclusion of a dosage per kilogram or per square meter. This allows the nurse and pharmacist to check not only the calculation but also the dosage equation used.

Reducing the risk for errors by using alternative dosage calculation techniques[15] or alternatives to the use of dosage regimen equations (ie, weight-based dosage ranges and tables) should be evaluated.[10,13,14] Caregivers need to be aware that the use of alternative dosing methods may also result in errors unless carefully designed and tested. Eventually, computerization of the medication order entry process may allow dosages to be calculated and checked more effectively by the computer based on predetermined formulae and appropriate patient parameters. Texts, handbooks, and manufacturer labeling (package inserts) are frequently consulted by clinicians for medication dosage recommendations in the form of equations. Such dosage recommendations should be consistently and clearly expressed to avoid confusion and reduce risk for misinterpretation or misreading. Improved training of clinicians in calculating dosages is necessary to reduce risk in situations in which calculations must be used.[3,4,9] All clinicians must be aware of the increased potential for confusion and error when calculations or complicated dosage equations are used and to take appropriate steps to avoid error.

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