The Benefit of Houseofficer Education on Proper Medication Dose Calculation and Ordering

LEWIS S. NELSON, MD, PETER E. GORDON, MD, MARC D. SIMMONS, MD, WILLIAM L. GOLDBERG, MD, MARY ANN HOWLAND, PHARMD, ROBERT S. HOFFMAN, MD

Abstract. **Objectives:** Drug dosing errors commonly cause morbidity and mortality. This prospective controlled study was performed to determine: 1) residents' understanding of drug dose calculations and ordering; and 2) the short-term effect of a brief educational intervention on the skills required to properly calculate dosages and order medications. **Methods:** The study was conducted at an urban public hospital with a four-year emergency medicine (EM) residency program. The EM residents served as the study group and were unaware of the study design. A written, eight-question test (T1) with clinical situations and factual questions was administered. Immediately following the test, correct answers were discussed for 30 minutes. Key concepts were emphasized. Six weeks later, a repeat test (T2a) with a similar format was administered to the study group. The same test (T2b) was simultaneously administered to a control group, residents of similar training who did not take T1, in order to determine test equivalency (T1 vs T2). Tests were graded using explicit criteria by a single investigator blinded to the order of administration. **Results:** Twenty residents completed both tests T1 and T2a. Their mean scores were 48% and 70%, respectively ($p < 0.001$, paired t-test). The control group of ten residents had a mean score of 49% (T2b), similar to the study group's scores on T1 (T1 vs T2b, $p = 0.40$, unpaired t-test). **Conclusion:** Emergency medicine residents require specific training in calculating and executing drug ordering. A brief educational intervention significantly improved short-term performance when retested six weeks later. Long-term retention is unknown. **Key words:** medical errors; medication errors; prescriptions, drug; education, medical; internship and residency. ACADEMIC EMERGENCY MEDICINE 2000; 7: 1311–1316

THE INSTITUTE of Medicine (IOM) report,[1] released in 1999, implicates medication errors as the direct cause of at least 7,000 patient deaths annually. These numbers are supported by the Harvard Medical Practice Study, published in 1991, which identified that nearly 4% of all patients admitted to hospitals in New York State suffered a consequential iatrogenic injury.[2] The apparently simple act of administering a medication is actually the culmination of numerous sequential steps, each with its own potential for error. Thus the causes of medication errors are diverse and span the spectrum from incorrect drug ordering to confusion between drugs with similar names to incorrect patient identification.

However, one of the leading causes of iatrogenic medical injury is incorrect drug calculations and ordering.[3] This type of error is implicated in up to 15% of all errors in medication ordering.[4] The problem is particularly prevalent in the practice of pediatrics, where weight-based calculations are needed for virtually every prescription.[5] Moreover, since children account for approximately 15% of emergency department (ED) visits, the impact of drug dosing errors in emergency medical practice is obvious.

Little formal education in dose calculations and order writing is typically offered in medical school or during residency. The assumption is that physicians learn this skill independently. Conventional medical education focuses on specific disease entities, likely to affect only a fraction of the patients for whom clinical care is rendered. Conversely, medication ordering affects virtually every patient by often imperceptible or delayed means. Given the large and increasing volume of patients passing through EDs nationally, even a trivial error rate may result in thousands of iatrogenic adverse events.

From the Department of Emergency Medicine, Bellevue Hospital Center/New York University School of Medicine, New York, NY (LSN; PEG; MDS; WLG; RSH); the New York City Poison Control Center, New York, NY (LSN; MAH; RSH); and St. John's University College of Pharmacy and Allied Health Professions, Queens, NY (MAH).

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Address for correspondence and reprints: Lewis S. Nelson, MD, 455 First Avenue, Room 123, New York, NY 10016. Fax: 212-447-8223; e-mail: lnelson@pol.net

1. A 5 kg child with congenital congestive heart disease requires digoxin at a standard dose (10 μg/kg). The available pediatric preparation contains 0.1 mg/mL. Write an order for the medication.

2. A 75 kg patient presents with hypoglycemia and you wish to administer 1 gm/kg of intravenous glucose.

   a. Please write an order for IV glucose for this patient.

   b. An amp of D50 contains 50 mL. How many grams of glucose are in this amp?

3. The maximal dose of subcutaneous lidocaine permitted for laceration repair is 5 mg/kg.

   a. What is the maximal number of "mL's" that a 60 kg patient may receive if a 2% solution is used?

   b. When used to describe liquid medications, the term percent (%) is equivalent to (i.e. % is the same as ___?): (one correct)

gm/L	gm/dL	gm/mL
mg/L	mg/dL	mg/mL
mEq/L	mEq/dL	mEq/mL
mmol/L	mmol/dL	mmol/mL

4. High dose epinephrine is administered to certain patients during cardiac arrest. A typical dose is 5 mg.

   a. If the epinephrine solution available contains 1:1000 epinephrine (typical subcutaneous epinephrine bottle), how many mL's of this mixture must be given to the patient?

   b. If a patient receives 1 mL of lidocaine containing epinephrine 1:100,000, how much epinephrine (in mg) did the patient receive?

   c. The term 1:1000 is equivalent to which:

gm/L	gm/dL	gm/mL
mg/L	mg/dL	mg/mL
mEq/L	mEq/dL	mEq/mL
mmol/L	mmol/dL	mmol/mL

Figure 1. Test questionnaire 1 (T1).

This study was designed to evaluate the baseline ability of emergency medicine (EM) residents to properly calculate and write orders for medications with complex dosage calculations. This is only one part of the entire process of medication delivery, but one that is amenable to correction through education. We hypothesized that a brief, focused educational effort directly aimed at improving residents' abilities to properly dose and order medications would have a measurable benefit when the residents were re-evaluated six weeks later.

METHODS

Study Design. This was a prospective study assessing the baseline ability of EM residents to calculate and prescribe complex medication orders. Additionally, the effect a brief educational effort had on the performance of these skills was assessed. This study was approved by the institutional review board and informed consent was obtained from each participant prior to each examination.

Study Setting and Population. All EM residents attending a weekly educational conference at a four-year (PGY 1–4) EM training program participated in this study. Conference attendance is mandatory for all EM residents currently assigned to the ED.

Study Protocol. A test questionnaire (T1) consisting of eight questions involving case scenarios was distributed to residents at a weekly conference. The case scenarios consisted of typical clinical situations in which a standard drug must be administered in a defined dose (Fig. 1). The study subjects were asked to calculate the appropriate dose with the given information and/or write an order for that drug. Additional factual questions regarding drug dosages and concentrations were included as well. All participants, regardless of their background, were asked to complete all of the questions, since the skills necessary to write a medication order are implicit in the duties of all participants. Ten minutes was allowed to answer the eight questions.

Immediately after the questionnaire, the correct responses were discussed in an educational session with the group for about 30 minutes, and all questions posed by the residents were answered. In addition, during the educational session certain key concepts, including the epidemiology of iatrogenic drug toxicity, were emphasized.

Six weeks later, a repeat test (T2a, Fig. 2) was administered to the same group that had previously completed T1. At the same time, this test (T2b) was administered to a control group of EM residents who had not been present six weeks earlier, had not taken T1, and had not received the brief educational intervention. The format of test T2 was similar to that of T1; only the drugs and dose calculations were altered. In order to limit bias, the study subjects did not know of the study ahead of time. Also, there was no suggestion that retesting would occur in order to eliminate additional preparation by the study group or advanced

1. A 10 kg child with a seizure requires phenytoin at a standard dose (15 mg/kg). The available pediatric preparation contains 0.1 g/2 mL. Write an order for the medication.

2. A 75 kg patient presents following a methanol overdose and you wish to administer 1 gm/kg of ethanol (po or iv) as a loading dose (this brings the blood alcohol level to about 100 mg/dL). The available pharmaceutical preparation is 5% ethanol in water.

   a. Please write an order for an IV ethanol loading dose for this patient.

   b. The legal limit for DWI is 0.1%. This is equivalent to (circle all that apply):

100 gm/L	100 gm/dL	100 gm/mL
100 mg/L	100 mg/dL	100 mg/mL
100 mEq/L	100 mEq/dL	100 mEq/mL
100 mmol/L	100 mmol/dL	100 mmol/mL

3. The maximal dose of subcutaneous lidocaine with epinephrine permitted for laceration repair is 7 mg/kg.

   a. What is the maximal number of "mL's" that a 10 kg patient may receive if a 1% solution is used?

   b. When used to describe liquid medications, the term percent (%) is equivalent to (i.e. % is the same as ___?): (one correct)

gm/L	gm/dL	gm/mL
mg/L	mg/dL	mg/mL
mEq/L	mEq/dL	mEq/mL
mmol/L	mmol/dL	mmol/mL

4. High dose intravenous epinephrine is used in some patients with cardiac arrest. A typical dose is 0.1 mg/kg.

   a. Write the order for high dose epinephrine for a 70 kg patient using 1:1000 epinephrine.

   b. The term 1:1000 is equivalent to which:

gm/L	gm/dL	gm/mL
mg/L	mg/dL	mg/mL
mEq/L	mEq/dL	mEq/mL
mmol/L	mmol/dL	mmol/mL

5. A 50 kg patient with a wrist fracture requires conscious sedation. The dose of fentanyl is 1 μg/kg and the available preparation is 0.05 mg/mL. Please write an order for intravenous fentanyl for this patient.

Figure 2. Test Questionnaire 2 (T2a and T2b).

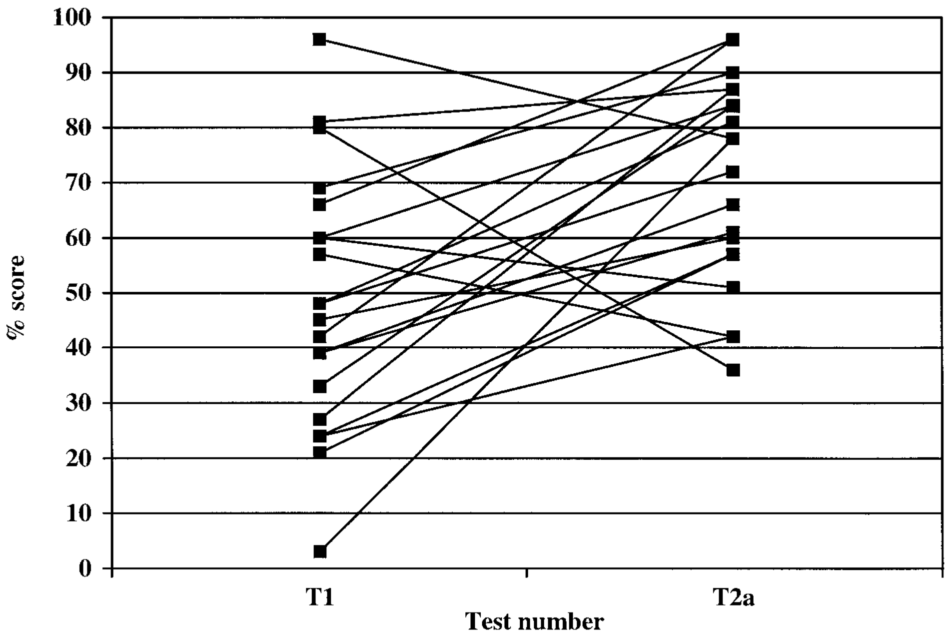

Figure 3. Trend in the scores of individual residents from T1 to T2a.

notice of testing for the controls. Entry into the control or study group was based on attendance at the conference; no other criteria were used.

Measurements. The tests (T1, T2a, and T2b) were graded using explicit predetermined criteria by a single independent investigator (PEG) blinded to the order of test administration and the identities (names and subject vs control status) of the residents. If appropriate, partial credit was awarded for incorrect answers if the correct conceptual process was documented on the examination sheet. Certain questions did not accommodate the assignment of partial credit, such as those where one best answer was to be identified from a list of choices.

Data Analysis. All participant information was entered into a Microsoft Excel 7.0 database (Redmond, WA). Distributions of the training levels among the study and control groups were compared using a two-tailed chi-square test. A two-tailed paired t-test was used to compare study participants' performances on tests T1 and T2a. A two-tailed unpaired t-test was used to compare the study group's performance on test T1 with the control group's performance on test T2b. A p-value of <0.05 was considered statistically significant.

Results

The study group consisted of 20 residents who completed both test T1 and T2a. The mean score (± standard deviation) of this group for test T1 was 48% (±23) and for T2a was 70% (±18) ($p < 0.001$, paired t-test). Eighty percent (16/20) of the study group obtained higher scores on the repeat test (T2a, Fig. 3). The control group contained ten residents who completed test T2b only. The mean score on this test was 49% (±19), which was similar to the study group scores on T1 (T1 vs T2b, $p = 0.40$, unpaired t-test).

The study group included more senior-level residents (PGY 3 and 4) than the control group ($p = 0.03$). The mean scores on T1 were 60%, 57%, 39%, and 53% for PGY 1, 2, 3, and 4 residents, respectively. The mean scores on T2b were 66%, 51%, and 39% for PGY 1, 2, and 3 residents, respectively. There were no PGY 4 residents in the control group.

Discussion

Despite numerous studies highlighting the morbidity and mortality associated with iatrogenic medication errors, this subject was rarely publicly discussed until recently. Medication errors may account for up to 54% of iatrogenic cardiac arrests, and many of these are presumably preventable.[6] Errors in drug administration include unintentional drug overdosing as well as underdosing; these may be unrecognized causes of treatment failure or side effects. Given the difficulty in simply defining and recognizing medication errors, accurately determining the incidence of the problem has proven difficult.[7]

Unlike other industries where emphasis in both training and practice is placed on the avoidance of error, such imposed conformity is often considered too intrusive in the practice of the art of medicine. However, as scrutiny of medication errors increased over the previous decade, and the scope of the problem was realized, mechanisms to reduce or eliminate such adverse events have been actively sought. Since dose calculation and ordering are an early step in the medication administration process, and are uniquely physician-based, intervention at this point could reduce the incidence of actual medication error. Instruction on proper medication ordering, unfortunately, has not traditionally been a significant part of formal medical education.

It appears that EM residents are in need of further education regarding medication ordering. This is clearly demonstrated by the 48% initial mean score on the examination. Similar results were reported among primary care and pediatric residents using a similar case-based format to ours.[8] Although testing is only a surrogate for actual clinical practice, we used realistic clinical scenarios. Whether this translates into an inability to perform under real clinical conditions, where more resources are normally available, is unclear. However, this examination tested concepts of dose calculation and order writing and not factual knowledge. All information required for deriving the correct dose was provided in the questions.

Testing using simulated clinical circumstances, followed by a brief period of discussion, provides immediate feedback for the resident concerning areas of educational need. Rather than education provided without a tangible clinical connection, as is often done with standard lectures, a targeted intervention provides contextual learning and may enhance interest and retention.

The 30-minute directed intervention described in this study produced a significant improvement in residents' abilities to successfully calculate complex medication dosages. The mean improvement was 30 points, and the majority of subjects showed an improvement in their scores. However, this study could not control for the effect of repetitive test taking, in which merely taking the initial test has a salutary influence on subsequent testing. The dramatic improvement using different questions suggests that this was not the sole influence on test improvement. Furthermore, even if the simple act of taking a test produced an improvement in this endpoint, the outcome would be equally valid.

The study and control groups differed in their distributions of residents based on level of training. The reason for this is unclear, since the conference is mandatory for all residents. It may reflect the greater availability of senior residents to attend the weekly conference because of their decreased clinical and off-service workload. Regardless, the importance of this difference may be limited, since the mean scores on both exams were independent of postgraduate year. That is, the ability to perform the calculations and ordering required for this exam did not improve in the expected fashion based on extent of prior training. The implications of this finding are unknown, but suggest that, without formal training, this skill may not be developed independently.

Several key issues remain. Overall, despite the improvement shown by our intervention, there is a need to augment EM residents' skills in this vital area. Even following the intervention, the physicians were only correct on 70% of the questions. Furthermore, while showing significant six-week improvement, this study does not address the issues of long-term retention.

Tremendous effort and expense is, appropriately, being invested to limit the occurrence of medication errors through the use of direct pharmacist participation,[9] computerized drug ordering systems,[10] and systematic changes in drug delivery. The primary responsibility for correct medication dose calculation and ordering remains with the prescribing physician. Emergency medicine residency programs may need to place greater emphasis on teaching these critical skills.

LIMITATIONS AND FUTURE QUESTIONS

This study has several potential limitations. The study and control groups differed in their distributions of residents based on PGY level of training. However, there did not appear to be an improvement in test scores as training level advanced. We used a question set that has never been formally validated. The fact that we observed residents from only a single residency program calls into question whether these results can be extrapolated to other EM residents. Additionally, the study group was limited to the number of residents available at our institution. Most importantly, while those residents who took part in the educational session had a marked improvement in their skills involving simulated dosage calculations and drug ordering, we did not assess such skills in a real clinical environment. Also, this study evaluated only the effect seen at six weeks; further study is warranted in order to determine whether these improvements persist.

CONCLUSIONS

A brief intervention regarding simulated drug dose calculations and medication ordering significantly improved the ability of EM residents to perform these critical tasks. Whether this effect persists beyond six weeks is unknown. The need for further improvement is evident.

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