
Personal digital assistant–based drug information sources: potential to improve medication safety*

By Kimberly A. Galt, PharmD, FASHP
kgalt@creighton.edu
Professor of Pharmacy Practice
Department of Pharmacy Practice

Ann M. Rule, PharmD
arule@creighton.edu
Clinical Assistant Professor of Pharmacy Practice and
Fellow, Center for Practice Improvement and Outcomes Research
Department of Pharmacy Practice

School of Pharmacy and Health Professions
Creighton University
2500 California Plaza
Omaha, Nebraska 68178

Bruce Houghton, MD
Houghton@creighton.edu
Assistant Professor of Internal Medicine
Department of Internal Medicine

Daniel O. Young, MD
dyoung@creighton.edu
Chief Resident, Internal Medicine
Department of Internal Medicine

Gina Remington, MD
gremingt@creighton.edu
Assistant Professor of Family Practice
Department of Family Practice

School of Medicine
Creighton University Medical Center
601 North Thirtieth Street
Omaha, Nebraska 68131

Objectives: This study compared the potential for personal digital assistant (PDA)–based drug information sources to minimize potential medication errors dependent on accurate and complete drug information at the point of care.

Methods: A quality and safety framework for drug information resources was developed to evaluate 11 PDA-based drug information sources. Three drug information sources met the criteria of the framework: Eprocrates Rx Pro, Lexi-Drugs, and *mobileMICROMEDEX*. Medication error types related to drug information at the point of care were then determined. Forty-seven questions were developed to test the potential of the sources to prevent these error types. Pharmacists and physician experts from Creighton University created these questions based on the most common types of questions asked by primary care providers. Three physicians evaluated the drug information sources, rating the source for each question: 1 = no information available, 2 = some information available, or 3 = adequate amount of information available.

Results: The mean ratings for the drug information sources were: 2.0 (Eprocrates Rx Pro), 2.5 (Lexi-Drugs), and 2.03 (*mobileMICROMEDEX*).

Lexi-Drugs was significantly better (*mobileMICROMEDEX t* test; $P = 0.05$; Eprocrates Rx Pro *t* test; $P = 0.01$).

Conclusion: Lexi-Drugs was found to be the most specific and complete PDA resource available to optimize medication safety by reducing potential errors associated with drug information. No resource was sufficient to address the patient safety information needs for all cases.

INTRODUCTION

Drug information sources readily available at the point of care is one practice-improvement intervention that may reduce medication errors [1]. Access to drug information sources in health systems and hospitals is considered a minimum standard. Typically, these resources are found in a version in print and for main frame or Internet access throughout patient care areas and professional areas such as the pharmacy and patient care units. Network access to drug information sources is also common in chain community pharmacies. Physician clinic practices have been less rapid to incorporate computerized drug information source access, however, and generally maintain a local centralized print library for drug information in the clinic itself. Despite the seemingly close proximity of many drug information sources, these sources are often not accessible under the efficiency constraints and clinical pressures most clinicians face. The process of readily accessing drug information in daily clinical practice needs systematic improvement [2]. The use of personal digital assistants (PDAs) has emerged as a technology that promises to improve the process of accessing drug information at the point of care for clinicians. Drug information resources have rapidly become available for use on the PDA.

Access to drug information at the point of care via PDA may have great potential to reduce medication errors associated with prescribing. Prescribing is the step in the medication-use process associated with the greatest proportion of documented errors. Further, it has been pointed out that the prescriber is the first individual in the medication-use process who can take steps to prevent error [3]. Most preventable adverse drug events occur in the prescribing stage of the medication-use process and have been attributed to inappropriate prescribing decisions and inappropriate monitoring [4]. What is the potential for PDA-based drug information sources to improve medication safety? The potential depends on the sufficiency of information available in software for these small, handheld computers.

This study compared the potential for PDA-based drug information sources to assure medication safety associated with specific, accurate, and complete drug information at the point of care. The objective of this

study was to determine the optimal drug information resource available on a PDA to use in daily clinical practice to meet this purpose.

METHODS

The project was conducted during the fall of 2002. A framework to describe the safety of drug information resources was developed and included traditional standards for evaluating the quality of drug information sources. The framework was used to evaluate eleven PDA-based drug information sources available at the time (Appendix A). The first step was to determine the indicators of a quality drug information source. Three of the eleven resources met all of the quality indicators and were selected for further study.

Next, safety indicators of a drug information source were determined. These two sets of indicators were used to develop a comprehensive set of questions to test the capacity of the drug information sources to answer drug information questions involving medication safety. Three general practice physicians agreed to serve as raters of the drug information sources. They were provided the questions and PDAs with the three drug information sources. The most sufficient drug information source to answer the safety-based questions was determined from these ratings. The specifics of this process are described here.

Quality and drug information sources

Quality indicator criteria were established based on the concept that the drug information resource must be sufficient to meet the drug information need when a question is posed. For a resource to be sufficient, it must be accurate, be complete, and meet the breadth, depth, and scope of information needed to answer a question. A comprehensive listing of general quality indicators of a drug information source was compiled by the primary investigator based on prior literature and evaluation of established published source books with general drug information [5-9]. A specific listing of the types of drug information that would be required to meet breadth, depth, and scope of a comprehensive drug information source was also compiled using the same technique.

These two listings were reviewed using a delphi group technique composed of three general practice physicians and three pharmacists. The final listing of quality indicators was transformed into a self-administered written survey to confirm those quality indi-

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Table 1
Physician-determined quality indicators for drug information sources

Quality indicator of a drug information source	Rank order of agreement (%)
Frequency that the information resource is updated	100%
Ease of use	100%
Degree of usefulness	100%
Information about drug interactions	100%
Information about adverse drug reactions	90%
Information about how the drug is supplied (i.e., available dosage forms)	90%
Credentials of the authors	90%
Information about dosing and schedule of medication use	90%
Information about age-adjusted dosing (i.e., pediatrics, geriatrics)	90%
Information about dose adjustment in renal impairment or hepatic failure	80%
Date the drug information resource is published	80%
Information about the drugs of choice for a particular condition	60%
Information about the therapeutic class of the drug of interest	50%
Information relevant to patient counseling about medications	50%
"Time lag," amount of time between new information availability and incorporation of this information into the information resource	40%
Information about compatibility or stability of drug products	40%
Bibliography associated with the information	20%
Information about the Drug Enforcement Agency (DEA) schedule of a drug	20%
Information about compounding and formulation of drug products	—

cators that physicians believed were important in drug information sources, with the types of information specifically identified. Physicians were chosen to evaluate this standard, because physicians generate the vast majority of prescriptions. A convenience sample of ten physicians in general primary care medical practice (five family practice, five internal medicine) completed the survey. The physicians in the convenience sample did not participate in the delphi group.

Safety and drug information sources

Drug information resource indicators for medication safety were determined. The classification system for medication errors from the National Coordinating Council Medical Error Reporting Program (NCCMERP) was assessed to determine the most common types of medication error likely to occur because of the lack of sufficient drug information at the point of care [10]. Safety indicators were derived based on this review. Error types were matched against the quality criteria to determine if each criterion predominantly related to a medication safety concern. In addition, each of the quality indicators was analyzed to determine their value to safety. Upon completion of this review, it was found that several indicators of quality represented the resources' likelihood of improving patient safety when prescribing took place (Appendix A).

Evaluation of personal digital assistant (PDA) drug information sources for quality and safety

Forty-seven drug information questions were developed to test the ability of the sources to meet the quality and safety criteria. The questions were based on three criteria: (1) information from the literature on the most common types of questions asked by primary care providers related to drug therapy, (2) content of questions representing commonly encountered clinical situations, and (3) representativeness of the questions of quality and safety indicators [5, 11–13]. Pharmacists

who have extensive practice experience answering questions posed by physicians initially developed the questions using these three criteria. A delphi group of general practice physicians and pharmacists reviewed and finalized the questions (Appendix B).

Analysis

The survey responses from the ten physicians to evaluate the quality indicators (Table 1) and the types of content that drug information sources should contain (Table 2) were summed and placed in rank order of agreement. The rank order of agreement was determined to assess what physicians thought were the most important areas of quality and content for a drug information source. This order was likely to represent the perceived frequency with which physicians believed they answered certain types of questions. All indicators were kept for this evaluation, because all indicators were necessary to assure that patient safety was optimized with the information source. Each of the eleven resources was evaluated using the quality indicators. Three resources—Eprocrates Rx Pro, Lexi-Drug, and *mobileMICROMEDEX*—met all of the identified quality indicators and were selected for comparative evaluation.

The questions were then used to test each of the three drug information sources. Three general practice physicians served as raters. Each was instructed to independently answer all forty-seven questions using each reference. The physician raters recorded answers to the questions and were then asked to assign a rating to each answer based on the extent to which the resource met the drug information need. The physicians were also asked to document discrepancies between the resources that might challenge the accuracy of the information. The ratings used were: 1 = no information available in the resource relevant to the information need; 2 = some information available, inadequate to meet the information need; or 3 = right amount of

Table 2
Physician-determined type of information needed in a drug information source

Type of information needed in a drug information source	Rank order of agreement (%)
Drug dosing and schedule of administration	100%
Information about drug interactions	100%
Information about available dosage forms of a drug	100%
Information about drug cost	100%
Information about risks during pregnancy	100%
Drug of choice and therapy alternatives for a condition or disease	90%
Alternative names for a drug (e.g., brand name, generic, or different brand names)	90%
Information about adverse drug events	90%
Information about side effects	90%
Information about drug use and breastfeeding	90%
Information about precautions and contraindications of a drug	90%
Drug dose adjustment recommendations for renal or hepatic impairment	70%
Information about overdoses or poisoning	70%
Information about herbal products and remedies	70%
Information to help identify a drug by description of the product (e.g., orange tablet with markings "XXX")	60%
Therapeutic indications for a drug	60%
Information about patient counseling considerations with a medication	60%
Information about the DEA schedule of a drug product	40%
Pharmacokinetic information about a drug	30%
Information about the compatibility/stability of a drug product	30%
Information about the mechanism of action of a drug	20%
Information about compounding or drug product formulation	10%

information available to meet the information need. The ratings were totaled, and an average score was calculated per physician rater for the resources. If a reference received an average score of 3.0, the reference would provide the right amount of information available for all of the questions used to test it. A perfect score of 3.0 would be the optimal reference.

Intra- and inter-rater reliability

An intra-rater comparison of the three references was performed and the significance set at $P = 0.05$ analysis of variance (ANOVA). The purpose of this comparison was to determine if each rater determined a difference between the three drug information sources. An inter-rater comparison for each reference was also performed, and the significance set at $P = 0.05$ (ANOVA). This comparison was performed to determine if the raters differed on a particular drug information source. The non-parametric Kruskal-Wallis test was also conducted to compare to the ANOVA because of the small sample size.

RESULTS

The mean ratings for sufficiency to meet the information need related to patient safety were: 2.00 (Eprocrates Rx Pro), 2.50 (Lexi-Drugs), and 2.03 (*mobile*-MICROMEDEX), respectively; with Lexi-Drugs signif-

icantly better when compared to *mobile*MICROMEDEX (t test; $P = 0.05$) and Eprocrates Rx Pro (t test; $P = 0.01$). No resource was sufficient for all 47 questions. The number of episodes with no or insufficient information were 19 (Eprocrates Rx Pro), 18 (*mobile*-MICROMEDEX), and 5 (Lexi-Drugs), respectively. None of the references were found to be inaccurate.

The intra-rater comparison revealed that Lexi-Drugs was rated significantly higher by two of the three raters when compared among the three references (AN-OVA $P < 0.05$; Kruskal-Wallis $P = 0.063$). The third rater rated Lexi-Drugs higher, with the difference detected at $P = 0.07$. There was no inter-rater difference in the ratings of the three physicians when each drug information reference was compared (Eprocrates Rx Pro $P = 0.99$, Lexi-Drugs $P = 0.32$, *mobile*-MICROMEDEX $P = 0.49$; Kruskal-Wallis $P = 0.49$) (Tables 3 and 4).

The physicians differed in their anecdotal impressions about the use of the information sources. Two of the three indicated they liked the completeness of the Lexi-Drugs resource; one stated, "it complements my knowledgebase," and another indicated it was so full of information that another resource would be sought because of a desire to have something quick. All commented that they found Lexi-Drugs' side scroll bar difficult to use. The evaluation of the three resources indicated that Lexi-Drugs was the most specific and complete drug information resource available via PDA

Table 3
Intra-rater comparison of drug information sources

Rater	<i>mobile</i> -MICROMEDEX average score	Eprocrates Rx Pro average score	Lexi-Drugs average score	Significance
Rater 1	2.1	2.0	2.4	$P = 0.07$
Rater 2	2.1	2.0	2.6	$P < 0.05$
Rater 3	1.9	2.0	2.6	$P < 0.05$

Table 4
Inter-rater comparison of drug information sources

Reference	Rater 1	Rater 2	Rater 3	Significance
<i>mobile</i> MICROMEDEX	2.1	2.1	1.9	$P = 0.49$
Eprocrates Rx Pro	2.0	2.0	2.0	$P = 0.99$
Lexi-Drugs	2.4	2.6	2.6	$P = 0.32$

to optimize medication safety in patient care at the time of the evaluation.

The small sample size is a consideration in this study. To be a comprehensive evaluation, a much larger sample of questions should be addressed. However, the goal was to make a sound, pragmatic recommendation to practice-based clinicians about the optimal PDA-based drug information service for use at the point of care when prescribing takes place. The evaluation achieves this goal.

DISCUSSION

Traditionally, drug information sources have been viewed from the context of optimizing drug therapy use. Enhanced access to drug information via the PDA has the potential to further this objective. However, optimizing drug use is not the same as promoting medication safety. Public awareness of the safety of medication use and the high priority society places on this subject suggest information sources should also be viewed as a form of intervention to improve patient safety.

The goal of safety is to eliminate risk, thus, eliminating harm. Toward this end, the Institute of Medicine called for a reduction in medical errors in the United States by 50% over a 5-year period [14]. This call to action is a direct result of a substantial body of literature about medical errors in the hospital setting, with the majority of this knowledge related to medication errors. What is an error? A reasonable definition has been offered that states, "An error is any preventable event that may cause or lead to inappropriate medication use or patient harm while the medication is in the control of the health care professional or patient" [14]. Conceptually, error should be considered as an event that occurred that should not have occurred. If the event led to inappropriate medication use, it is an error. This event may or may not have resulted in patient harm.

Examination of the concept of medication error from this point of view makes clear that drug information sources must have specific information that is sufficient to meet the basic information needs of each clinical decision made in the process of medication use. "Sufficient" means that the information needs can only be met if the information is accurate, specific, and complete enough to meet clinical practice needs. Therefore, listing dosage forms for an oral antibiotic, such as ampicillin, as "capsule, suspension, injection" would not be considered sufficient. Although accurate, the description is not specific or complete enough for a clinician to actually prescribe or recommend the regimen using the suspension product. What is the concentration of ampicillin in the suspension? How does one accurately recommend a dose, based on milligrams of ampicillin and volume to administer per dose? In this example, the drug information reference is insufficient to minimize dosing errors. The information should include strength and/or concentration to be sufficient.

A single drug information product cannot stand

alone to fulfill all critical patient care information needs. The need for a complete library that is readily accessible to clinicians continues. The comprehensiveness of Lexi-Drugs was found to be a trade off for quickness of information retrieval. However, all physician raters commented that they found the resource easy enough to use in exchange for the depth of information. This comment is important in the context of medication safety at the point of prescribing, when the information must adequately provide the basic detail necessary to correctly write a complete prescription. It is noteworthy that another independent study found Lexi-Drugs an excellent source for assessing drug interactions compared to other PDA software applications [15].

One valuable safety addition to PDA drug information sources would be product identification, such as information about capsule or tablet color, markings, and sizes. This information was not available through any of the three resources evaluated but was commented on by the physician raters. Pictures of each dosage form would be ideal but not practical because of the large amount of memory that the typical PDA would require. Another suggestion was to provide a bibliography to support clinical information. Having access to the literature citations would strengthen the drug information conclusion.

Adverse drug events that are simply listed in the drug information source do not provide enough information to improve decisions related to a medication's safety. They should be listed by severity and/or frequency. Listing adverse events by system would enable the user to quickly find important information, and information about the likelihood of adverse events was commented on as useful. Lexi-Drugs lists adverse drug events by frequency.

The cost of drugs is not related to medication safety directly but is related to medication adherence. Lexi-Drugs and Eprocrates Rx Pro both list the average wholesale price (AWP) of each drug. The AWP is not the price charged to patients, distributors, or other intermediaries and does not consider the patient's prescription drug benefit or actual cost of the medication. However, practitioners find this feature useful when prescribing medication.

Computerized practitioner order entry, integrated electronic medical records, and clinical decision support systems must be designed with patient safety as a core framework. The implications of this work are applicable to these developing systems. Patient safety improvements that depend on information systems will only be as effective as the potential they are designed to meet.

CONCLUSION

Lexi-Drugs was the most specific and complete resource available via PDA to improve medication safety by reducing potential errors associated with insufficient or incomplete drug information. However, no resource sufficiently addressed the patient safety infor-

mation needs for all cases. As with print libraries, utilizing more than one resource is often necessary to provide the most accurate and complete information. Specific suggestions for improving any drug information source to improve medication safety are to include information on the stability of drug products and descriptions of the drug dosage form for identifying the product. Clinicians should evaluate future drug information sources by their ability to meet medication safety needs.

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APPENDIX A

Framework for drug information resource safety and quality criteria

Safety and quality indicator	Check (✓) if this characteristic is a safety indicator	Check (✓) if this characteristic is a quality indicator
Date the drug information resource is published		✓
Frequency that the information resource is updated		✓
Credentials of the authors		✓
"Time lag," amount of time between new information availability and incorporation of this information into the information resource		✓
Breadth of drug entities available, including older acceptable treatments	✓	
Presence of a list of references or bibliography associated with the information		✓
Ease of use of the resource		✓
Degree of usefulness of the resource		✓
Information about adverse drug reactions	✓	
Depth of information related to possible drug-induced side effects of commonly used agents	✓	
Depth of information about how the drug is supplied (i.e., available dosage forms)	✓	
Presence of information about compatibility or stability of drug products	✓	
Presence of information about compounding and formulation of drug products		✓
Presence of information about dosing of medication	✓	

Depth of information related to dosing regimen recommendations specific to indications for use	✓	
Depth of information related to dosing regimen recommendations related to initiating therapy, specific to indications for use	✓	
Dose adjustment guidelines available based on body weight, when applicable to drug	✓	
Presence of information about age-adjusted dosing (i.e., pediatrics, geriatrics)	✓	
Presence of information about dose adjustment in hepatic impairment	✓	
Presence of information about dose adjustment in renal impairment	✓	
Presence of information available to make dose adjustments in response to serum level monitoring, when appropriate for the drug	✓	
Presence of information about the drugs of choice for a particular condition		✓
Presence of information about the therapeutic class of the drug you are interested in		✓
Presence of information about the Drug Enforcement Agency schedule of a drug		✓
Presence of information relevant to patient counseling about medications	✓	
Depth of information related to indications for use		✓
Presence of information about drug interactions	✓	
Breadth of information about possible drug interactions with herbal products	✓	
Breadth of information about possible drug interactions with older agents	✓	
Drugs of choice and therapy alternatives for a condition or disease		✓
Alternative names for a drug (e.g., know the brand name, need to know the generic, or need to know different brand names)	✓	
Information to help identify a drug by description of the product (e.g., orange tablet with markings "XXX")	✓	
Information about drug cost		✓
Information about screening tests to prevent use of drug in a patient predisposed to toxicity	✓	
Pharmacokinetic information about a drug		✓
Information about risks during pregnancy	✓	
Information about drug use and breastfeeding	✓	
Information about excessive doses, overdoses, or poisoning	✓	
Depth of information about herbal products and remedies	✓	
Information about the mechanism of action of a drug		✓
Depth of clinical guidance for unusual clinical situations associated with commonly used drugs	✓	
Breadth of drug entities available, including over-the-counter products	✓	
Breadth of drug interaction information available, including over-the-counter products.	✓	
Depth of information about precautions and contraindications of a drug	✓	

APPENDIX B

Drug information questions used to compare drug information sources

1. What is the recommended dosage regimen for use of reserpine in treatment of hypertension in an adult male who is fifty-eight years old?
2. What is the initial recommended starting dose for tolbutamide in an adult who has adult-onset diabetes mellitus?
3. What are the active ingredients in Cosopt?
4. Is it possible that diltiazem causes gingival hyperplasia?

5. What are the most common side effects of isosorbide dinitrate?
6. What are the top drug interactions I should worry about for a man who is on Aldomet?
7. Are there any cautions or concerns about the use of isoniazid in a woman who is thirty-eight years old?
8. What should be done about a patient's warfarin therapy; the patient is scheduled to have a wisdom tooth extraction two weeks from now?
9. Is there a commercially available garlic concentrate capsule? I have a patient who has heard of this and wants to start taking one.
10. Is there a drug interaction between warfarin and garlic?

11. My patient wants to take vitamin E concentrate. Is there a commercially available product?
12. My patient is on warfarin. Is there a drug interaction between warfarin and vitamin E?
13. I would like to restart Prozac and delivered a baby two weeks ago. Will this drug go into my breast milk?
14. I have been on Dilantin and just learned that I am pregnant. Will I be able to continue taking Dilantin throughout the entire pregnancy? Is there any evidence about teratogenicity?
15. Should I adjust the dose of this patient who is on Dilantin? Based upon her serum creatinine, I estimate her creatinine clearance to be about twenty milliliters per minute (mls/min).
16. Is hydrochlorothiazide a good choice in the management of edema in my congestive heart failure patient? She has a creatinine clearance estimated at twenty to twenty-five mls/min (she is eighty-three years old).
17. My patients renal function is deteriorating, and I have her on tobramycin. Are there any concerns about adverse effects or precautions?
18. My patient's liver function tests are rising quickly; I have her on itraconazole. Are there any concerns about adverse effects or precautions?
19. My patient is taking warfarin 7.5 milligrams per day orally and has come to clinic with an international normalized ratio (INR) of six. What should I do?
20. A little boy who is eight years old just ate a bottle of FeSo₄ tablets his mother had in the kitchen. She thinks he ate forty or fifty of them. What should I do?
21. This adult will not swallow capsules, and it is essential that he be treated with a macrolide antibiotic. Is there an injectable, long acting macrolide that can be given in the office?
22. What is the cost of Ditropan XL?
23. What are the key counseling points that are important about the use of topical nitroglycerin paste?
24. What is the mechanism of action of Paxil?
25. What is the stability of ampicillin oral suspension once it is reconstituted?
26. A patient just asked me if I could compound a ketorolac (or EMLA or Brompton's cocktail) topical cream. Is there a formulation for this?
27. My patient is taking OxyContin thirty milligrams by mouth (per os) every (mg po q) twelve hours for severe pain. How should I prescribe it?
28. What is the dosage of Augmentin suspension in a four-year-old female patient (fifty pounds) with acute otitis media?
29. What is the dose of Tranxene for an eighty-five-year-old woman with anxiety?
30. What is the maximum daily dose of Darvocet N 100?
31. How do you prescribe Percocet for the pain associated with an acute ankle injury (twisted ankle) from playing tennis? The ankle was twisted yesterday and is now swollen and tender. The patient is forty-five years old.
32. What is the equivalent dose of Lipitor to Zocor?
33. How long should I wait after a myocardial infarction to start warfarin therapy in a fifty-five-year-old man?
34. Does Zithromax work for community acquired pneumonia?
35. How effective is Zolof in the management of premenstrual dysphoric disorder?
36. How long does the sexual dysfunction (decreased libido) associated with Zolof last after stopping it?
37. Above what dose of potassium chloride as a daily oral supplement does hyperkalemia develop?
38. Is Verapamil contraindicated in pregnancy?
39. Are there any interactions between amoxicillin and food?
40. What is the brand name for sertraline?
41. How much hydrochlorothiazide is in Dyazide?
42. What is the active ingredient in Lanoxicaps?
43. What are the available dosage forms and strengths of digoxin?
44. How do the absorption and duration characteristics of Calan and Calan SR compare?
45. What is the mechanism of action of Zithromax?
46. What is the cost of Humulin N?
47. How often should a phenytoin serum level be drawn in a patient with grand mal seizures who is stable and well controlled on phenytoin?