Using Information Technology to Reduce Pediatric Medication Errors

Christoph U. Lehmann, MD, and George R. Kim, MD

Abstract

• **Objective:** To describe efforts in medication error prevention and reduction at an academic children’s medical center.

• **Methods:** The general process used involved (1) identifying “broken” medication processes using “tribal knowledge” and formal data collection, (2) designing solutions using developers with multiple domain (clinical and programming) expertise, (3) implementing integrated applications using a local area network and limited-scale, Web-based information technology solutions, and (4) evaluating the results using defined measures and user surveys.

• **Results:** Error rates were reduced. Contributory factors included user satisfaction secondary to reduced workload and the perception of a safer work product.

• **Conclusion:** Information technology can reduce errors by streamlining repetitive processes and simplifying complex ones.

Health care processes, due to their complexity, are highly vulnerable to errors. Of all medical error types, those involving medications are among the most frequent [1]. In most cases, medication errors and their adverse effects are preventable [2]. Preventable adverse drug events have been estimated to account for as much as 41% of all hospital admissions and inpatient costs of more than $2 billion annually [3]. For children, medication error rates have been estimated to be triple those found in adults [4]. Universal pediatric requirements for age-, weight- and body surface area–based drug dosing make pediatric prescribing more complex and thus more vulnerable to error than prescribing for adults.

Drug errors may occur at any step of the medication process—ordering, monitoring, transcribing, dispensing, or administering [5,6]—but have been observed to occur most frequently during the ordering phase [7,8]. Error reduction/prevention efforts have been aimed at reducing vulnerabilities during ordering, including problems with legibility and formatting, confusion of similar drug names, and errors in calculation. A primary approach to reduce errors, promoted by health care and patient advocacy groups [9], has been the adoption of information technology (IT), such as computerized physician order entry (CPOE) and computerized decision support in processes such as medication ordering.

IT applications can reduce and prevent medication errors by standardizing repetitive (high-volume) tasks and simplifying complex (error-prone) tasks. CPOE can streamline drug prescription by preventing unwanted variations in orders by guiding user choices and inputs and by facilitating clear communication and transcription. Computerized decision support can guide drug selection and dose calculation by providing just-in-time formulary knowledge [10] to alert prescribers to contraindications [11], such as overdoses, allergies, and drug-drug interactions, by combining automated calculations and knowledge from the electronic medical record and evidence-based guidelines [12].

In this paper, we describe efforts in error reduction and prevention at an academic children’s center using an approach of identifying error-vulnerable (“broken”) medication processes, designing and implementing directed, Web-based IT solutions, integrating the solutions into existing workflows, and evaluating the result and effect of the solutions.

Setting and Leadership

The described projects were undertaken at the Johns Hopkins Children’s Medical and Surgical Center in Baltimore, MD, a comprehensive, tertiary, acute care pediatric facility. The Center annually admits 7800 inpatients with 24,000 outpatient visits for a wide range of complex health problems. The 180-bed facility provides extensive pediatric services in critical care, neonatal intensive care, oncology, general surgery, and a variety of other subspecialties.

All projects reported in this paper were supported by an ongoing quality and patient safety improvement initiative by the Children’s Center leadership supported by the Josie King Safety Fund [13]. The projects were developed and implemented through the director of clinical information technology at the Children’s Center in conjunction with...
PEDIATRIC MEDICATION ERRORS

pharmacy and the Johns Hopkins Medicine Center for Information Services.

General Structure and Process
The projects rely on an organizational structure that includes the following:

- **Local area network (LAN):** A secure electronic information network is used to link computers from patient care units and the pharmacy to a common network and to allow sharing of information and resources. Patient units and pharmacy (as well as other departments) can communicate with each other from computer workstations using standard information and communication protocols similar to those used for the internet. Clinical messages generated, transmitted, and received using these protocols can be machine-processed for use in transactions and decisions.

- **Rapid application development environment:** All described applications were developed using a commercially available programming tool that allows quick and facilitated development of forms and interfaces (for users to enter data at bedside computer workstations) and rule programming for computerized decision support. The tool, which uses Web-based technology, facilitates development within the LAN, reduces development time because it uses a common and reusable set of software components, and eliminates the need to install the new software on all computers.

- **Small, cross-trained project development team:** A small “incubator” group of self-motivated developers supported and directed by the organizational leadership, whose members have multiple expertise in both clinical and information functions and workflows, allows flexibility and perspectives that promote innovation and efficiency in development. The small size and multiple expertise of the team reduce the need for meetings and discussions and allow rapid decisions and adjustments in programming and implementation of solutions.

The general process of the approach is:

- **Identify the problem**—Find the “broken” process
- **Design and implement a solution**—Fix the “broken” process
- **Evaluate the result**—Amend or extend the solution as appropriate

Specific Projects and Outcomes
TPNCalculator
Identifying the problem. Pediatric pharmacists at our center observed that the paper-based process of ordering total parenteral nutrition (TPN) within the neonatal intensive care unit (NICU) was flawed; errors with significant potential for morbidity occurred frequently and repetitively. A literature review revealed this to be a common problem and source of adverse events in NICUs in general [14,15].

Consideration of the TPN ordering process by a neonatologist, a nutritionist, and a pharmacist led to identification of its vulnerabilities. TPN orders were typically written on a standard paper form by residents based on current laboratory results (sometimes unavailable) and rule-based guidelines (sometimes misremembered or misapplied). The deadline for TPN orders, noon for a given day, provided additional time pressure and opportunity for errors in the already busy and distracting clinical environment of the NICU. Identified error vulnerabilities of the TPN process included legibility problems, calculation and dosing errors, omission and/or inappropriate use of specific agents (eg, heparin and insulin), and osmolality errors.

Implementing a solution. A Web-based TPN order entry system (TPNCalculator) was created and introduced to the NICU [16] as part of a quality and safety improvement initiative. TPNCalculator was designed and implemented by a team consisting of a neonatologist/programmer, pediatric nutritionist, and pharmacist using Web technology and deployed on the local area network connecting NICU workstations to the pharmacy. TPNCalculator standardizes the repetitive process of TPN ordering by guiding prescriber entry through a standard Web-based interface. The interface strongly resembles the pre-existing paper form (to increase familiarity, facilitate transition, and reduce the risk for new types of errors). With support of staff from neonatology, nursing, nutrition, and pharmacy, TPNCalculator was easily integrated into the neonatal TPN ordering workflow.

TPNCalculator automates all necessary fluid and TPN component calculations based on guided input through a standard Web-based form. It employs nutritional guidelines, an osmolality calculator, and 62 rule-based alerts and reminders to reduce and prevent prescriber errors (Figure 1). Alerts and reminders include checks for age/weight ratio, dose ranges (based on total dose, dose per weight, concentration, and percentage of total calories) for all components. The appropriate protein additive based on age is selected automatically, and an osmolality alert is triggered conditionally for peripheral (noncentral) lines. Reminders for phosphorus, calcium, and heparin (for central lines) are provided.

The complexity of reminders is based on previous entries. For example, if a prescriber chooses to omit the default dose of...
trace elements (ie, selenium, zinc, chromium), she/he will be prompted to add each one individually and a rule to check dose ranges of each will be activated. Entered data are validated with computerized rules (eg, continuous infusions cannot exceed 24 hours), and patient-specific information (date of birth, medical record number, name) is automatically populated from other hospital systems. Prescribers may reuse knowledge from previous orders (such as fluid volume or amino acid type), thus reducing the potential for keyboard entry errors.

Evaluating the result. Before implementation, 10.8 errors per 100 orders were detected, compared with 4.2 errors per 100 orders with the initial use of TPNCalculator. Initial feedback was used to modify the calculator and resulted in a further error reduction to 1.2 errors per 100 orders (89% overall reduction in error rate). Modifications in response to subsequent user feedback resulted in the addition of specific dose range checks, a fluid volume calculator to check for precipitation and mandatory data elements. In addition, the interface was modified to include frequently used shortcuts to improve workflow per users’ suggestions. Prescribers expressed significant satisfaction with TPNCalculator and judged it to be superior to the paper ordering system. Users stated that TPNCalculator was easier to learn and use than and was a general improvement over paper ordering. Perhaps of greatest importance was that users reported that it protected them against making errors and saved them time.

Because we focused on a single area of concern and used a small dedicated team with domain knowledge, the total development time was only 3 weeks despite the wide range of safety features. As a result of demonstrated error reduction and user satisfaction, use of the TPNCalculator, originally designed for NICU, was extended to the entire Children’s Medical and Surgical Center within a month of roll-out. Further modifications, such as improved search capability, have been made in response to user requests.

TPNCalculator has been in continuous use at the Children’s Center since 2000 and has been extended to 3 different institutions, with more than 45,000 TPN orders written. In comparison with a commercial CPOE product currently in use, TPNCalculator has been found to provide superior decision support and has been retained as the standard institutional TPN ordering tool.

Infusion Calculator

Identifying the problem. Errors in ordering continuous intravenous (IV) infusions in pediatrics are a frequent and well-known problem. Ordering IV forms of drugs requires more knowledge and accuracy by prescribers than for other forms of medication [17,18]. Potential toxicity of IV medication overdoses makes the impact of errors higher than for other routes. In addition, patients requiring continuous infusions are usually located in busy, distracting clinical environments, which may increase the frequency of errors. Complexity is
increased if a patient receives multiple infusions, which further increase the potential for errors.

For adults, infusions contribute 106 errors per 1000 patient days, with incorrect infusion rates representing over 40% of all intensive care unit errors [5]. In children, the chance for errors is higher because of adjustments due to frequent weight changes. In a pharmacy review at the Children’s Center, the rate of infusion ordering errors was found to be 27% [19]. The most common errors found in continuous infusion medication orders were wrong concentration, wrong dose, incorrect calculation rule application, and missing data elements.

Implementing a solution. Using an approach similar to that used to implement TPNCalculator, a Web-based calculator for prescribing continuous infusions was created. The calculator was designed and implemented by a team of a neonatologist and pediatric pharmacists and deployed to the Center’s neonatal and pediatric intensive care units. The infusion calculator simplifies the complex process of ordering continuous infusions by automating calculations and providing knowledge-based alerts (initially based on “Rule of Six” [20] calculations and then on standard concentrations, per the Joint Commission on Accreditation of Healthcare Organizations 2005 Patient Safety Goal mandate) based on prescriber data entered via a standard Web-based interface designed to simulate the traditional paper-based continuous infusion order form.

The infusion calculator guides prescriber data entry with default doses and minimum/maximum dose ranges. Based on patient weight, selected drug and dose, carrier fluid and volume, and standard concentration, the calculator determines the flow rate (Figure 2). Prescribers are alerted to inappropriate carrier fluid choices, inappropriate doses, and insufficient infusion volumes (Figure 3). The initial version of the calculator provided support for 32 infusion medications. Calculation and alert rules were adapted from Johns Hopkins protocols and reference materials such as the Harriet Lane Handbook [21] and were validated by 2 pharmacists.

The calculator generates a legible printed order that is faxed to the pharmacy and placed in the patient’s chart. The pharmacy transcription step, already in place, uses a separate computer system.

Evaluating the result. Based on data collection in the pediatric pharmacy, calculator-generated infusion orders had 83% fewer (P < 0.001) orders containing 1 or more errors (6% versus 33%). Handwritten orders contained more high-risk errors (incorrect decimal, dose, unit of measure) and required more pharmacist interventions. Calculator-generated orders contained no high-risk errors (26% versus 0).

Use of the infusion calculator has been extended to and is now mandatory for all pediatric patients at the Children’s Center receiving continuous IV medication infusions.

Antibiotic Approval System

Identifying the problem. Problems of escalating antibiotic resistance and difficult-to-treat infections resulted in the recognition of the need for good antimicrobial stewardship [22]. Inclusive in the initial plan was an organizational strategy at the Children’s Center to require prior approval by a member of the infectious disease (ID) division for certain antibiotics. As the annual number of approval requests increased from 600 to over 2000 during years 2001 to 2005, observed errors in the request procedure included no written

![Figure 2. Infusion calculator. Note that insulin is defaulted to be delivered in normal saline. Insulin does not allow the provider to order a flow rate as it is dispensed in a ready to use concentration.](image-url)
Implementing a solution. In conjunction with ID specialists, a centralized Web-based antibiotic approval, tracking, and pager-based notification system was created. The application streamlines the repetitive process of antibiotic approval by providing prescribers with computerized decision support for determining the appropriateness of an approval request and simplifies the complex and error-prone process of tracking the duration of approvals. It automates the repetitive processes of notifying ID and pharmacy staff by pager of approvals and of alerting prescribers of imminent approval expirations (to reduce both antibiotic overuse and missed/delayed doses).

The application manages antibiotic therapy by requiring all prescribers to register in the system. Prescribers ordering antibiotic therapy must log into the secure application Web site (available through patient care workstations). A prescriber selects patient and antibiotic and is prompted to enter the reason for the request (using a checklist of common reasons or free-text entry) and pager/callback numbers (Figure 4). When the request is submitted, the information processed and immediately sent by pager through an institutional online pager system to on-call pharmacist and ID fellow.

If the ID fellow has additional questions, he/she contacts the prescriber directly. The ID fellow approves or rejects the request through a Web-based interface and a notification is paged to the provider and the pharmacists. To streamline the approval process, certain reasons are granted automatic approval (eg, vancomycin for a serious gram-positive infection in a patient with a severe allergy to β-lactam antibiotics). Requests between 11 PM and 7 AM are approved automatically for 1 or 2 doses until 8 AM.

Each morning, all expiring approvals trigger a page being sent to the ID service and to the original prescriber for reconsideration. Through different Web-based forms integrated into the system, ID fellows can review and manage all requests and approvals, and nurses can search for approvals on their patients.

Evaluating the result. The system was implemented in June 2005 and detailed evaluation data are still pending, but initial user satisfaction feedback with the antibiotic approval process has improved dramatically. Anecdotal evidence indicates shortening of antibiotic courses and fewer delays in first dose delivery. In the first 2 weeks of system operation, 105 antibiotic requests resulted in 69 approvals (65%), of which 12 were automatic (no direct ID fellow involvement).

Factors for Success

Organizational Support
A strong organizational leadership that supports error reduction is essential to the survival of these and other error reduction projects and initiatives. In addition to organizational leadership endorsement, collaboration among different disciplines is vital to success. All of the described projects have the
common factor of organizational support and cooperation of domain experts from pharmacy, nursing, nutrition, and providers in the development and testing of applications.

**Tribal Knowledge**

The use of “tribal knowledge” [23] by inclusion of staff in the error identification process is also important. Tribal knowledge is any unwritten information known to experienced personnel that may be required to produce a quality product or service. The presence of certain error types or vulnerabilities, well-known internally by staff and personnel, may go unaddressed unless a proactive initiative or sentinel event brings them to attention for formal analysis and correction. Relevant tribal knowledge may be captured through inclusion of staff members in the error identification process and asking them to point out process vulnerabilities and recurrent errors. In the cases described, the identification of errors and vulnerabilities, implementation of solutions, and selection of evaluation parameters used local tribal knowledge and informal agreement among the staff.

**Defined (Small) Scale of Initial Project**

In all the described applications, a deliberate attempt was made to “find and fix” the “broken” link (the step or steps in the clinical process directly responsible for a specific medication error type), and to avoid changing the remaining parts of the process. In general, the larger and more complex the project, the greater the need for formalization of each of these steps to keep all members of the project team informed and to keep the project on track. In these small-scale solutions, the multiple roles of individuals helped to keep formalization and development time down.

**Practical Usability**

When possible, Web-based form interfaces were designed to match existing paper forms to provide users with a familiar format and to reduce the introduction of (new) cognitive errors due to workflow change [24]. This approach had the apparent (and intended) effect of minimizing the need for extensive re-training of users and facilitated successful integration of the designed solutions into workflow.

**Multiple Expertise**

Multiple expertise [25] among team members in clinical domains, clinical and electronic information workflows, and programming reduces the time needed to design, implement, and deploy an application. A clinician-programmer (in contrast to a programmer without clinical domain expertise) has
implicit knowledge of clinical processes and can integrate clinical algorithms and their exceptions into programming code, reducing the cognitive and administrative overhead needed to translate knowledge. The use of participant/observers (prescribers and pharmacists) in multiple roles also shortens the testing and evaluation cycle, including analysis (application usage, resource utilization, patient care issues, and failure modes).

**Strong Network Structure and Support**

The common IT environment and the Web-based approach to solutions facilitated the expansion of these projects. Because the IT network is both generic and similar throughout the Children’s Center, many of the patient care structures (workstations, connections) and processes (medication ordering, administration) are similar, and therefore the same “fixes” are applicable. Although these projects began as small-scale interventions, their facilitated adoption by the entire institution (through a common IT framework) amplified their overall impact.

**Rapid Evaluation and Iterative Deployment**

Iterative formative evaluation of the structure and process/outcome effects of these interventions allowed ongoing correction as evaluation data became available. Both qualitative (user surveys, informal meetings) and quantitative (comparison of defined process measures pre- and postintervention) methods were used to measure acceptance and success of interventions.

**Conclusion**

As data from successful (and unsuccessful) IT deployments are published, the collected evidence may help guide effective error reduction strategies. While many institutions use and show CPOE to reduce errors [26], there is growing perception that the current generation of commercially available applications may not yet provide the depth of decision support required to facilitate error-free performance of clinical tasks [27], such as weight-based prescription of continuous infusions, chemotherapy, or TPN. Error reduction due to CPOE will likely succeed with development and implementation of flexible and usable knowledge management tools that facilitate translation of guidelines into IT algorithms to provide effective decision support [28].

The approach we describe has achieved success, we believe, by marshalling tribal knowledge and collecting data to identify and define broken processes, by leveraging an existing IT network to best advantage, and by providing focused IT solutions of limited scope to fix them by streamlining repetitive tasks and simplifying complex ones. This “find it and fix it” approach limits efforts to specific solvable problems and leaves the remaining system intact. This approach, however, may not be useful for problems that cannot be well defined or agreed upon, and although it may carry a greater risk for software design flaws, it can be used successfully by using participant/observers in the development and evaluation cycle, with additional gains of early implementation and cost reduction.

Corresponding author: Christoph U. Lehmann, MD, Johns Hopkins University School of Medicine, Nelson 2-133, 600 N. Wolfe St., Baltimore, MD 21287.

**References**