

Grant Final Report

Grant ID: 5 UC1 HS015319

Evaluating the Impact of an ACPOE/CDS System on Outcomes

Inclusive dates: 09/30/04 - 09/29/07

Co-Principal Investigators:

Sean D. Sullivan, PhD, University of Washington
Albert W. Fisk, MD, MMM, The Everett Clinic

Team members:

Emily Beth Devine, PharmD, MBA^{* †}
David K. Blough, PhD^{* †}
William Hollingworth, PhD^{* †}
Thomas H. Payne, MD^{* †}
Jennifer Wilson-Norton, RPh, MBA^{* ††}
Nathan M. Lawless, ChE, RPh^{* ††}
Richard J. Rafoth, MD^{* ††}

David R. Dixon, MD, BSc, MCLSc(FM),
CCFP[‡]

Bryan A. Comstock, MS^{†, ††}

John Scehovic[§]

Larry Schecter, MD^{§§}

Ryan N. Hansen, PharmD^{** †}

Kerry Kelly, RPh^{** †}

* Co-Investigator

** Research Associate

† University of Washington

†† The Everett Clinic

‡ Byron Village Medical Centre, London ON

†† Biostatistician

§ CliniTech® Information Services

§§ Providence Everett Medical Center

Performing Organizations:

University of Washington, and The Everett Clinic

Project Officer:

David Meyers, MD

Submitted to:

The Agency for Healthcare Research and Quality (AHRQ)

U.S. Department of Health and Human Services

540 Gaither Road

Rockville, MD 20850

www.ahrq.gov

Abstract

Purpose: The project consisted of two aims: 1) Implement an ambulatory, computerized prescriber order entry (ACPOE, e-prescribing) system with basic clinical decision support (CDS) alerts; capture lessons learned; and evaluate workflow/workload and human factors impacts on prescribers and staff); and 2) Evaluate the impact of the system on medication safety—medication errors and adverse drug events.

Scope: The Everett Clinic is a community-based, multispecialty health-system. The e-prescribing system was implemented at all sixteen sites (60 clinics). Comparing pre- to post-implementation, the workflow/workload and human factors evaluations took place at three primary care clinics; the medication safety evaluation at all clinics.

Methods: Roll-out was staggered. Throughout implementation, iterative improvements were made and lessons learned captured. Workload/workflow was evaluated by a time-motion study; human factors impacts were captured from focus groups and a survey instrument. Ten thousand prescriptions were evaluated to identify and characterize prescribing-related errors.

Results: All clinics are now using the e-prescribing system. Staggered roll-out, iterative improvements, individual training, and real-time availability of technical assistance enabled successful adoption. Use of the system was time-neutral for prescribers. End-user feedback was positive. E-prescribing resulted in a reduction of (potential) medication errors from 28% to 9%.

Key Words: e-prescribing, time-neutral, decreased errors

The authors of this report are responsible for its content. Statements in the report should not be construed as endorsement by the Agency for Healthcare Research and Quality or the U.S. Department of Health and Human Services of a particular drug, device, test, treatment, or other clinical service.

Final Report

Purpose

The project consisted of two over-arching aims and five sub-aims.

Aim 1

Implement the ambulatory computerized prescriber order entry (ACPOE) system, now called the electronic prescribing (e-prescribing) system, in all practice sites within The Everett Clinic, by the end of the calendar year 2009.

Aim 1a: Describe the steps taken, strategies used and lessons learned that enabled successful implementation.

Aim 1b: Evaluate the impact of the e-prescribing system on organizational workload and workflow processes. We measured pre- and post-implementation metrics that characterized these processes. To achieve this aim our primary activity was to conduct a direct observation time-motion study that assessed the time-intensity of e-prescribing, comparing it to hand-written prescribing. Secondary metrics captured included the proportion of prescribers voluntarily using the system, the number of paper charts pulled per month, and the number of dispensing pharmacies to which electronic prescriptions were auto-faxed. We posited that implementation of the e-prescribing system would improve workload and workflow efficiency, as determined by these metrics.

Aim 1c: Evaluate the impact of the e-prescribing system on the human factors aspects of the implementation. Human factors can be defined as the relationship between human beings and the systems in which they work.¹ To achieve this aim we used two methods: focus groups and a survey instrument. In the focus groups, we explored and described prescriber and staff (end-users) experiences with and perceptions of the e-prescribing system. Using the survey instrument, we assessed whether end-users indicated increased comfort with the e-prescribing system over time; and whether self-assessed computer knowledge correlated with overall survey scores. We posited that experiences would be largely positive (focus groups), and that those who had integrated computer use into their professional lives would be more comfortable using the system (survey).

Aim 2

Evaluate the impact of the e-prescribing system on medication safety, specifically, medication errors and adverse drug events.

Aim 2a: Compare the epidemiology of prescribing errors (characteristics and severity), comparing those that occurred pre- to post-implementation. We posited that the frequency of errors would decrease, and that the error characteristics would change. We posited that the e-prescribing system would largely impact errors associated with a basic e-prescribing system, such as errors due to improved legibility.

Aim 2b: Investigate the relationship between medication errors, identified in Aim 2a, and downstream adverse drug events (ADEs). By linking prescriptions to subsequent admissions to the inpatient services or emergency department at the local hospital, we investigated the relationship between medication errors and potential ADEs, and determined the characteristics of errors that contribute to ADEs. By linking prescriptions to hospital admissions, we hoped to gain insight into the types of errors that contribute to morbidity. We posited that few errors would result in ADEs. We considered Aim 2b a descriptive and hypothesis-generating aim.

Scope

Background

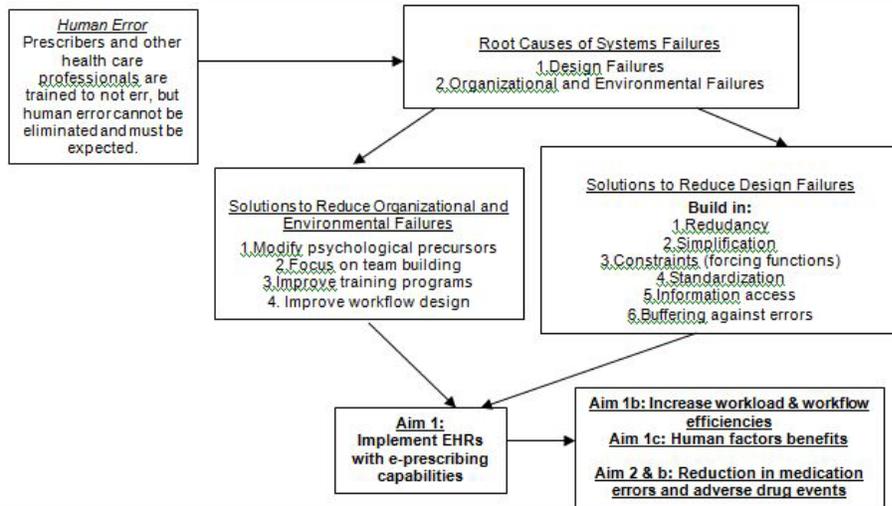
During the 1990's the impact of health information technology (HIT) solutions on medication errors and ADEs was studied extensively by Bates and Leape.² But it was not until the publication of *"To Error is Human"* (IOM-1999)³ that the issue of patient safety was brought into the national spotlight. E-prescribing has emerged as a viable option for reducing errors, while increasing efficiency.² However, these systems have not yet been perfected.⁴ Prior to study launch, most research evaluating computerized provider order entry (CPOE) systems had been conducted in the inpatient setting; primarily in academic medical centers². However, the majority of US healthcare is delivered in community-based ambulatory settings⁵, where the use of ambulatory (A)CPOE systems is low and research questions about how these systems impact workload efficiency, end-users perceptions and experiences, and medication safety, remained largely unexplored.

Conceptual Model and Research Framework

We adapted our conceptual model and research framework from work in the field of human error and system design⁶, and its application to the medical field.⁷ (Figure 1) Reason⁶ and Leape⁷ present a theory of cognition that describes human error and state that it cannot be eliminated. They suggest that systems should be developed that decrease the frequency with which humans make errors, thus mitigating the harm that ensues. The model illustrates that the root causes of systems failures stem from either design of the systems, or from the organizations and

environments that use them. Solutions to systems errors lay in these same two categories. Applying these concepts to our research, we accepted that humans will err and that we must implement systems, that is, e-prescribing systems in the context of electronic health records (EHRs), that reduce errors. We posited that the introduction of an e-prescribing system would improve workload and workflow efficiencies, be perceived positively by end-users, and reduce errors related to the prescribing process.

Figure 1. Conceptual model and research framework for implementing and evaluating an e-prescribing system^{6,7}



Setting

The Everett Clinic is a vertically integrated, multispecialty physician group practice that provides comprehensive, community-wide health care for the northern Puget Sound area. Over 275 physicians (200 of which are physician-owners) deliver comprehensive care in sixteen ambulatory locations, in over sixty clinics. There are three pharmacies on-site. The single hospital in the local market, Providence General Medical Center, is a part of the multi-hospital Providence Health System. A hospitalist team from The Everett Clinic cares for these patients when they are admitted – providing continuity of care between the ambulatory and inpatient settings. The Everett Clinic cares for 225,000 patients and logs over 700,000 ambulatory care visits annually. Prescribers write over 2.5 million prescriptions annually.

The Everett Clinic has developed and maintains a full array of HIT services through its wholly owned subsidiary, CliniTech®. From 1995 onward, CliniTech® employees have been responsible for development and implementation of The Everett Clinic’s internally developed (“homegrown”) EHR and e-prescribing system. The EHR integrates patient scheduling, chart notes, laboratory values, imaging reports and, most recently, basic e-prescribing into one system. The e-prescribing system is web-based and utilizes a commercial drug-database. Prescribers can electronically prescribe new and refill prescriptions, and can auto-fax these to over 500 dispensing pharmacies in the area. The system optimizes the selection of medications, generates

real-time medication lists, calculates pediatric antibiotic dosing by weight, and populates disease management registries.

A coupling of The Everett Clinic's core value of innovation, strong leadership, and a strong HIT department, with an understanding of their own and current national health care trends, led The Everett Clinic to prioritize implementation and evaluation of the e-prescribing projects supported by this grant.

Participants

In 2002, leaders at The Everett Clinic invited University of Washington (UW) faculty members (SDS and EBD) to collaborate with them as TEC set out to implement their basic e-prescribing system and to evaluate the impact of this system on medication safety. This pilot work enabled our team to compete successfully for this AHRQ HIT Implementation grant in 2004 (UC1 HS015319-03; PI: Sean Sullivan). Having assembled a strong research team has enabled successful completion of all aims of this grant. The full complement of investigators is listed on the title page of this document.

Methods

Aim 1: Implement the Ambulatory Computerized Prescriber Order Entry (ACPOE) System, Now Called the Electronic Prescribing (e-Prescribing) System, in all Practice Sites within The Everett Clinic, by the End of the Calendar Year 2009

Aim 1a: Describe the Steps Taken, Strategies Used and Lessons Learned that Enabled Successful Implementation.

Aim 1a: Study Design. We accomplished Aim 1a by recording the various aspects of implementation throughout the implementation process. We discussed the implementation process weekly throughout the three-year period. During these discussions we recorded in an MS Excel™ spreadsheet all steps taken, strategies used, and lessons learned during the implementation process. One of the UW investigators maintained the spreadsheet. Near the end of the grant cycle we reviewed the spreadsheet and categorized each entry topically.

Aim 1a: Inclusion/Exclusion Criteria. The inclusion criteria for this aim were very broad. Our goal was to capture everything that could be directly or tangentially related to e-prescribing implementation. As such, we included steps, strategies and lessons related to not only to system implementation, but also to system development and testing, maintenance, security and organizational culture.

Aim 1a: Data Sources. All investigators contributed lessons to this aim. Additional lessons were provided by leadership, prescribers and clinic staff at The Everett Clinic, and reported to the UW investigators.

Aim 1a: Evaluation Methods/Data Analysis. Evaluation was limited to consolidating entries in the Excel™ spreadsheet, eliminating redundancies, and categorizing entries into five categories: system development and testing, implementation, maintenance, security, and organizational culture.

Aim 1a: Limitations. The results of this aim were limited to the steps, strategies and lessons captured from implementation of a homegrown e-prescribing system in a community-based, multispecialty health system.

Aim 1b: Evaluate the Impact of the e-Prescribing System on Organizational Workload and Workflow Processes. We measured pre- and post-implementation metrics that characterized these processes. To achieve this aim our primary activity was to conduct a direct observation time-motion study that assessed the time-intensity of e-prescribing, comparing it to hand-written prescribing. Secondary metrics captured included the proportion of prescribers voluntarily using the system, the number of paper charts pulled per month, and the number of dispensing pharmacies to which electronic prescriptions were auto-faxed. We posited that implementation of the e-prescribing system would improve workload and workflow efficiency, as determined by these metrics.

Aim 1b: Study Design. We conducted the time-motion study at three clinic sites within The Everett Clinic: Silver Lake, Harbour Pointe, and Snohomish. We collected two rounds of data, each representing a unique combination of the stages of e-prescribing implementation. In the first round we collected cross-sectional data; data collected in the second round will enable us to make longitudinal comparisons. The primary focus of the longitudinal analysis was the Silver Lake site, as this was the only site where a transition was made from a prescribing process that was entirely handwritten, to one that is now managed by e-prescribing. Although the original study design varied from what is described herein, adjustments were made based on a revision in the implementation strategy that was directed by The Everett Clinic. Specifically, The Everett Clinic originally had planned to deliver their e-prescribing software on wireless laptops provided to prescribers. However, network challenges caused them to revise this plan and to, instead, hardwire each examination room with a desktop computer. This change necessitated a modification to the original study design, and resulted in the comparisons described in Table 1 below.

Table 1. Clinic sites & stages of e-prescribing implementation used in the time motion study

Clinic	Stage of e-Prescribing Implementation: First Round of Data	Stage of e-Prescribing Implementation: Second Round of Data
Silver Lake	Paper	Desktop computer in exam rooms and at common work stations
Harbour Pointe	Prescriber: desktop computer in office; Staff: desktops at common work stations	Desktop computer in exam rooms and at common work stations
Snohomish	Prescriber: personal wireless laptops; Staff: desktops at common work stations	Desktop computer in exam rooms and at common work stations

Aim 1b: Inclusion/Exclusion Criteria. We included primary care clinics at these locations: family practice, internal medicine, pediatrics and walk-in clinics. All prescribers were invited to

participate, as was staff whose job descriptions in any way included the management of prescriptions. Each site employs 8-15 prescribers and between 13 and 25 staff.

Aim 1b: Evaluation Methods. We used time-motion methods to evaluate prescriber and staff tasks. Time-motion methods are considered the gold standard for capturing workflow and workload data, as they capture the subject's tasks continuously throughout a set time interval. We collected the cross-sectional data sequentially from February 2005 through January 2006; the longitudinal data from November 2006 through May 2007. A total of six observers collected data, two conducted the majority of the observations. Each received training in time-motion methods. One observer shadowed each prescriber and staff member for one, four-hour time interval (morning or afternoon), during each of the two study timeframes. We collected the data using Timer Pro™ software (Applied Computer Services Inc., Englewood, CO) on a Palm® Tungsten handheld PDA device. We used task categories that we modified from the work of Overhage.⁸ Additional detail of our time-motion methods can be found in our recently published manuscript.⁹

Written consent was obtained from all prescribers and staff who participated. Although the study did not capture any patient-related information, all patients provided verbal consent to have an observer shadow their provider in the examination room. The UW Human Subjects Committee approved all study activities.

Aim 1b: Data Analysis. Data stored on the PDA were downloaded into MS Excel™ for analysis. Our aim was to measure the uptake of e-prescribing and to determine the time-intensity for prescribers and staff. First, we examined the time spent on major task categories (e.g. computer versus writing tasks), measuring the impact of e-prescribing on overall workload and workflow. We used unpaired t-tests to calculate the mean difference, in minutes per hour that prescribers and staff spent on various task categories at each site and stage of implementation. Second, we compared only prescription-related events performed by prescribers and staff at each stage of implementation, using as a metric the number of seconds per prescription-related event. For this analysis, we used a linear mixed effect model to compare prescription event times, using new/refilled prescriptions as a fixed effect, and site (cross-sectional analysis) and prescriber (longitudinal analysis) as random effects. Third, we calculated the proportion of prescriber and staff time spent in the re-categorized tasks (i.e. direct or indirect patient care). We externally validated the TM data by comparing it to data captured in the practice management system. Analyses were conducted in SPSS™ 13.0, R™, or Stata 10™ statistical software.

We applied a power calculation to estimate the significance of the difference in time spent prescribing between the paper-based and the e-prescribing methods within the Silver Lake site (longitudinal analysis). Using pilot data to estimate the mean number of seconds per prescribing event and a variance inflation factor that accounted for clustering of prescriptions within each prescriber, the study had 95% power to detect a 20% change in number of seconds for each prescribing-event.

Aim 1b: Limitations. The major limitation of this study was that tasks conducted outside the four-hour observation time blocks were not captured. Specifically, prescribing-events conducted during lunch hours or in the evenings were not captured. A second limitation was that the identification and categorization of clinical tasks, especially when clinicians were multi-tasking, was imperfect. Third, generalizability may be limited to clinics where the patient mix is

similar to The Everett Clinic's. The average age of The Everett Clinic population is 45 years; the number of medications prescribed is known to increase after this age, and this may impact the amount of time spent prescribing. Finally, generalizability may be limited to similar, community-based clinics that have implemented a homegrown EHR and basic e-prescribing system.

Separately, each of the secondary process metrics was captured throughout the three-year study timeframe: the proportion of prescribers voluntarily prescribing electronically and the number of pharmacies to which prescriptions were auto-faxed were captured from the e-prescribing system and the EHR. The number of chart pulls was captured from The Everett Clinic's practice management system. Each metric was summed and graphed quarterly.

Aim 1c: Evaluate the Impact of the e-Prescribing System on the Human Factors Aspects of the Implementation. Human factors can be defined as the relationship between human beings and the systems in which they work.¹ To achieve this aim we used two methods: focus groups and a survey instrument. In the focus groups, we explored and described prescriber and staff (end-users) experiences with and perceptions of the e-prescribing system. Using the survey instrument, we assessed whether end-users indicated increased comfort with the e-prescribing system over time; and whether self-assessed computer knowledge correlated with overall survey scores. We posited that experiences would be largely positive (focus groups), and that those who had integrated computer use into their professional lives would be more comfortable using the system (survey).

Aim 1c: Study Design—Focus Groups. We conducted focus groups with end-users at the same three primary care clinics at which we conducted the time-motion study – Silver Lake, Harbour Pointe and Snohomish. Data reflected the same three unique stages of e-prescribing implementation as were reflected in the first round of data collection for the time-motion study, thus representing a cross-sectional comparison. We used semi-structured elicitation techniques. A priori, we created a conceptual model (Figure 2) and a template of research questions to guide and focus the discussion, one each for prescribers and staff. The theoretical framework was developed from the work of Reason⁶, Leape⁷, and Dixon^{10,11}, and included domains identified from the literature, a priori. The templates consolidated these domains into four broad categories: expectations, impact, and fears of e-prescribing, and barriers to e-prescribing. Each template also included probes and ended with an open-ended question that invited participants to convey information not already covered.

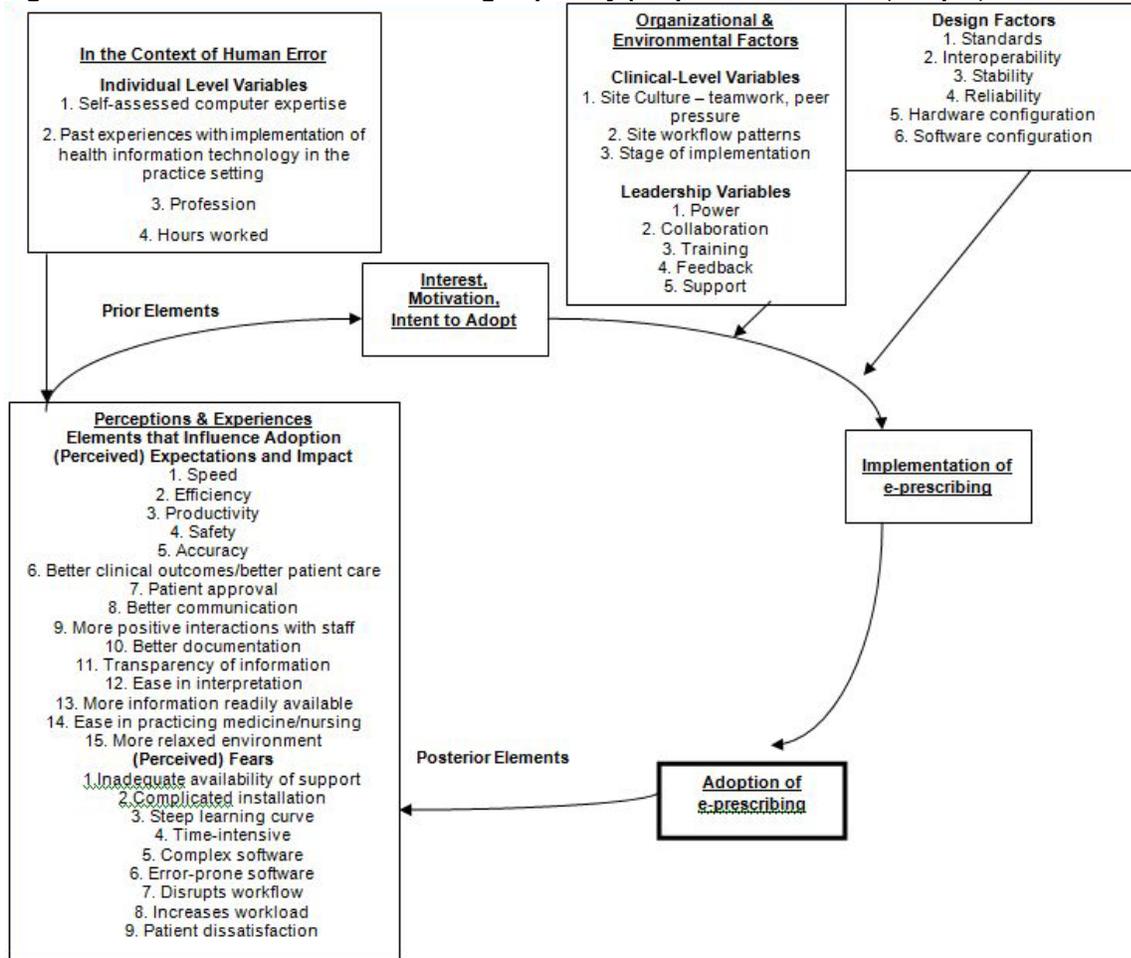
Aim 1c: Study Design—Surveys. The survey portion of the human factors study was conducted in parallel with the time-motion study. The end-users at these same three clinics were invited to complete a survey at each of the two times of their observation for the time-motion study, thus allowing us to assess computer adoption as implementation progressed at these three sites. All end-users were invited to complete the survey; participation was voluntary. All provided informed consent.

The UW Human Subjects Committee approved both the focus group and the survey studies.

Aim 1c: Execution of Study. At study outset, an orientation meeting was conducted at each site. Orientation to the time-motion study, the focus group study, and to the survey study was provided at the same meeting. At this time, all end-users were invited to participate in all three aspects of the e-prescribing project. Thus, the sampling frame was universal.

Aim 1c: Execution of Study—Focus Groups. At each clinic we conducted one focus group for prescribers and one for staff. One additional focus group was conducted for “float pool” staff – staff that rotated among clinic sites. Verbal consent was provided at the outset of each focus group. One of the UW investigators facilitated each focus group. Each focus group lasted thirty minutes.

Figure 2. Theoretical framework for focus group study (adapted from Reason⁶, Leape⁷, and Dixon^{10,11})



Aim 1c: Surveys. We utilized a survey instrument developed by Dixon^{10,11}, intended to assess IT adoption behaviors. The instrument is based on a conceptual model called the Technology Assessment Model, first developed by Davis, which includes theories of innovation diffusion and technology acceptance.^{12,13} The instrument, “Information Technology in Family Practice”, assesses finesse (defined as the ability and willingness to transfer knowledge and skills from one task to another), intent to use, perceived usefulness and perceived ease of use. Its reliability and validity have been demonstrated in a group of family physicians.¹⁰ We adapted this 37-question survey instrument that assesses adoption, calling it “Information Technology in Primary Care Practice”. A 38th question elicits information about self-assessed computer knowledge.

Aim 1c: Evaluation Methods/Data Analysis—Focus Groups. A non-participating research associate recorded discussions on a laptop. The categories from the templates became the “start lists” when coding transcripts. Open coding was used to begin the process of thematizing responses. Individual codes were categorized into families of codes; then into themes. The unit of analysis was each focus group. The themes were compared across each focus group, determining similarities and differences in responses between types of end-users, and between clinics. All analyses were conducted using Atlas.ti™ (Berlin, Germany).

Aim 1c: Evaluation Methods/Data Analysis—Surveys. Survey data were entered into an Excel™ spreadsheet and are being analyzed in Stata, Version 10™. The 37-item survey summary score assesses overall comfort with using the computer system. We use this summary score as a proxy for adoption of the e-prescribing system. We utilized the answer to the 38th question, about self-assessed computer knowledge, to determine if this self-assessment correlated with adoption, measured by the summary score.

Scores from the surveys are being analyzed using a longitudinal analysis. For prescribers, we are using generalized estimating equations (GEE) to account for the correlation among scores obtained from the same subject. The data for the staff are anonymized, so will not be correlated by subject. For staff, we will use analysis of variance techniques and change scores to determine e-prescribing acceptance comparing the two time points.

Aim 1c: Limitations—Focus Groups. The data from the focus group study provide a cross-sectional sampling of end-users thoughts and feelings, reflecting different stages of e-prescribing implementation. Participation in the focus groups was voluntary, so the sampling frame may be biased. As the results are from primary care clinics within a health-system that has implemented a homegrown e-prescribing system, results may not be generalizable to other settings or to specialty clinics. Finally, qualitative research always carries the bias of the investigator who collected and analyzed the data. This limitation is inherent in all qualitative methods.

Aim 1c: Limitations—Surveys. There are two limitations to the survey. First, this is the first time that the survey instrument, intended to assess overall computer use by family practice physicians, has been used to assess e-prescribing use by other types of primary care physicians. Second, although we have paired data on each participating prescriber, at two time-points, our data on staff was provided anonymously. We are therefore unable to conduct the same pairwise, longitudinal comparisons among staff. For the latter group, our analyses are limited to comparing results at the group level.

Aim 2: Evaluate the Impact of the e-Prescribing System on Medication Safety, Specifically, Medication Errors and Adverse Drug Events

Aim 2a: Compare the Epidemiology of Prescribing Errors (Characteristics and Severity), Comparing Those That Occurred Pre- to Post-Implementation. We posited that the frequency of errors would decrease, and that the error characteristics would change. We posited that the e-prescribing system would largely impact errors associated with a basic e-prescribing system, such as errors due to improved legibility.

Aim 2a: Study Design. This study was a retrospective cohort review of 10,000 prescriptions and charts for the identification and characterization of medication errors, comparing those that occurred pre- to post-e-prescribing implementation; 5,000 in each time frame. This sample size provides 80% power to detect a 5% reduction in errors, from a baseline error rate of 25%, using a 2-sample, 2-sided, χ^2 test of equal proportions, with an alpha level of 0.05. The prescriptions representing the pre-implementation timeframe were hand-written a minimum of six months prior to the implementation of the e-prescribing system, and those representing the post-implementation timeframe were electronically written a minimum of six months subsequent to the implementation of the system. Prescriptions were identified in reverse chronologic order for the former timeframe and in chronologic order for the latter timeframe. The samples were weighted to reflect the prescribing patterns of all prescribers (primary care and specialty care), and the five top therapeutic drug categories, seen throughout The Everett Clinic for a 12-month timeframe. The sample was limited to prescriptions filled at any of the three TEC pharmacies. The UW Human Subjects Committee approved the study.

Aim 2a: Inclusion/Exclusion Criteria. Both new and refilled prescriptions were included. Prescriptions transferred into or out of one of The Everett Clinic's pharmacies were excluded. Prescriptions for devices, laboratory supplies and chemotherapeutic agents were excluded.

Aim 2a: Data Sources. Data sources were the prescriptions, all documentation contained in the EHR, and the prescription as entered into the pharmacy dispensing system.

Aim 2a: Evaluation Methods. Two clinical pharmacists independently evaluated each prescription. Each prescription was evaluated for the presence of an error. If an error were present it was then characterized, using categories identified from the literature a priori (e.g. illegibility, drug-disease interaction), and a severity weight assigned. We adopted the severity weighting schema of the National Coordinating Council on Medication Error Reporting and Prevention (NCC MERP).¹⁴ We adopted and codified decision rules, a priori. We assessed concordance using the kappa statistic; three of the investigators resolved discrepancies. We recorded data in an MS Access® database created expressly for this purpose. A detailed description of the methods we used to conduct this study can be found in our manuscript published in the AHRQ volume *Advances in Patient Safety: From Research to Implementation*¹⁵.

Aim 2a: Data Analysis. The prescription was the unit of analysis. The first outcome of interest was whether an error (or potential error) occurred. The second outcome was whether or not a serious medication error occurred (letters C through I using the NCC MERP¹⁴ criteria). The primary explanatory variable was e-prescribing implementation. As the outcomes are binary,

and the data are hierarchically structured (prescriptions within prescribers, within specialties, within clinic site), we used alternating logistic regression to estimate the effect of the stage of implementation on the outcomes. We adjusted the models for season of the year to reflect seasonal variations in prescribing patterns; number of weeks since implementation to account for secular trends; therapeutic drug class, new or refill prescription, and patient age.

Aim 2a: Limitations. There were two limitations to this study. First, the data collection methods precluded a definitive evaluation of the outcome of errors in patients; that is, whether errors caused harm. Although the EHR contains chart notes of all scheduled visits, a paper chart still exists, and a review of these would have been necessary to conduct a comprehensive evaluation of ambulatory visits related to downstream events caused by a medication error. Neither did the methods used in this study include contacting patients to determine if they received their prescription or adhered to their medication regimen. In order to make full use of the spectrum of severity levels offered by the NCC MERP Index¹⁴, a comprehensive review of these aspects of care would have been necessary. Importantly, however, in Aim 2b we linked patients whose prescriptions were reviewed for this study, to downstream inpatient admissions or emergency department visits to the local medical center (Providence Everett Medical Center).

Aim 2b: Investigate the Relationship between Medication Errors Identified in Aim 2a, and Downstream Adverse Drug Events (ADEs). By linking prescriptions to subsequent admissions to the inpatient services or emergency department at the local hospital, we investigated the relationship between medication errors and potential ADEs, and determined the characteristics of errors that contributed to ADEs. By linking prescriptions to hospital admissions, we hoped to gain insight into the types of errors that contribute to morbidity. We posited that few errors would result in adverse drug events. We considered Aim 2b a descriptive and hypothesis-generating aim.

Aim 2b: Study Design. This study was a retrospective chart review (both paper and EHR) to identify preventable ADEs; that is, ADEs that were caused by a medication error. All patients for whom a prescription was written and contained in the dataset for Aim 2a were included in Aim 2b. A patient identification number was assigned for patients for whom these prescriptions were written, and for whom a subsequent hospital admission or emergency department visit at Providence Everett Medical Center was recorded within 90 days of the prescription having been written. The UW Human Subjects Committee approved the study.

Aim 2b: Inclusion/Exclusion Criteria. We included all admissions for which the implicated medication could have caused the ADE. We excluded admissions for which the admission or procedure was unrelated to the prescribed medication (e.g. elective knee replacement or uncomplicated vaginal delivery matched to a prescription for a nasal steroid).

Aim 2b: Data Sources. In addition to the three data sources utilized in Aim 2a, by creating a link between each prescription and a subsequent hospital admission, we were able to review the medical record for these patients from Providence Everett Medical Center.

Aim 2b: Evaluation Methods and Data Analysis. In addition to each patient identifier and medication prescribed, we collected patient demographic information, discharge diagnosis-

related group (DRG) codes and descriptions, and discharge International Classification of Diseases, 9th Revision, Clinical Modification (ICD-9-CM) codes and descriptions. In addition to reviewing each ADE for its preventability, that is, its potential cause being the medication for which the prescription was written, we reviewed each ADE for its severity (significant, serious, life-threatening, or fatal), and ameliorability, using criteria established by Morimoto and colleagues¹⁶. We used the Naranjo probability scale to assess the probability of the ADE as an outcome (definite, probable, possible, doubtful).¹⁷ We created the ADE data elements collection form by combining the FDA MedWatch Form¹⁸ and the IOM's "Domain Areas for a Common Patient Safety Reporting Format".¹⁹ For those incidents that are classified as an ADE, we created a case summary describing the event, and any pertinent information about the underlying cause of the ADE.

Aim 2b: Limitations. This study was limited to ADEs that resulted in hospital or emergency department admission. We recognize that not all admissions necessarily occurred at Providence – although it is the only hospital in the state where The Everett Clinic physicians have admitting privileges. Administrative records at the hospital were not specific enough to perfectly identify the causal linkage between a prescription error and the admission. Finally, our dataset is limited to matches that were found using the DRGs and ICD-9-CM codes assigned at discharge for billing purposes.

Results

Principal Findings and Outcomes

Aim 1: Implement the Ambulatory Computerized Prescriber Order Entry (ACPOE) System, Now Called the Electronic Prescribing (e-Prescribing) System, in All Practice Sites within The Everett Clinic by the End of the Calendar Year 2009. Implementation proceeded much more quickly than was originally scheduled. The system was implemented and being used voluntarily by 100% of prescribers by October 2006. A detailed description of the development and implementation of the e-prescribing system can be found in our manuscript²⁰ that we recently submitted for consideration for publication in the AHRQ Patient Safety compendium, entitled, "*Advances in Patient Safety: New Directions and Alternative Approaches*".

Aim 1a: Describe the Steps Taken, Strategies Used and Lessons Learned that Enabled Successful Implementation. In this same manuscript²⁰ we describe in detail the steps used in the implementation process, the challenges encountered and the strategies used to solve each one, and the lessons learned that enabled successful implementation. The lessons learned encompass five domains: 1) development and testing, 2) implementation, 3) maintenance, 4) security, and 5) organizational culture. Lessons learned during implementation can be further categorized into those that involve networking, training, prescribers and staff, pharmacies, patients, and workflow and room configuration. The major lessons include that a positive, team-oriented organizational culture and visionary leadership are critical; that iterative implementation can be highly successful; that ongoing and readily accessible training is necessary; that involvement of

clinicians in every facet of development achieves buy-in; that workflow redesign is an integral facet of implementation; and that implementation is a journey, not a solution.

Aim 1b: Evaluate the Impact of the e-Prescribing System on Organizational Workload and Workflow Processes. The results of the cross-sectional analysis of the time-motion data have just been published.⁹ In this evaluation, 27 prescribers and 42 staff were observed. At the two sites with optional e-prescribing, 75% to 86% of prescription-related events were performed electronically. Prescribers at the e-prescribing sites spent significantly less time on writing tasks (-3.0 minutes/hour) but this time-savings was offset by increased computer tasks (3.9 minutes/hour). After adjusting for site, prescriber and prescription type, e-prescribing tasks took marginally longer than hand-written tasks (12 seconds). Nurses spent 5.4 minutes longer per hour conducting computer tasks than their counterparts at the paper-based site. However, when computing and writing tasks were combined, the difference between sites was not statistically different. At all three sites, nurses spent only 1.1 minutes / hour on prescription-related tasks. At the e-prescribing sites, medical assistants spent a non-significantly greater amount of time conducting computer-related tasks (3.4 minutes / hour), and conducting prescription-related tasks (0.6 minutes / hour). We are currently analyzing the second round of data from the time-motion study, and conducting the longitudinal analysis.

Secondarily, data on the following metrics have been collected: the proportion of prescribers prescribing electronically (Figure 3a) and the number of paper charts pulled per month at the Marysville site (Figure 3b). The graphs of each metric over time indicate the uptake of the e-prescribing system. Separately, the number of pharmacies to which prescriptions are auto-faxed is now over 500.

Figure 3a: Proportion of prescribers prescribing electronically

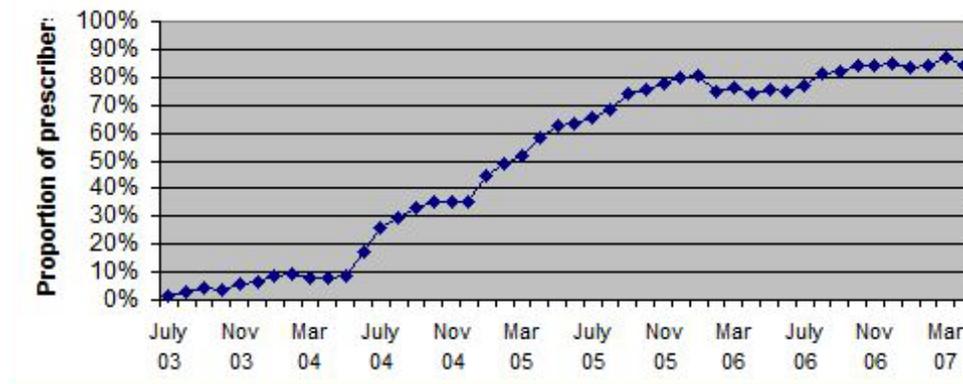
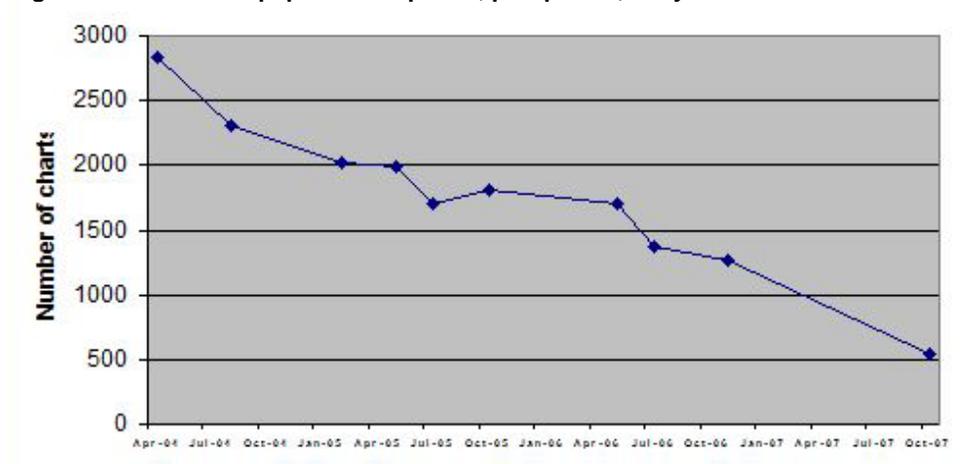


Figure 3b: Number of paper charts pulled, per quarter, Marysville site



Aim 1c: Evaluate the Impact of the e-Prescribing System on the Human Factors Aspects of the Implementation: Focus Group Study. We conducted a total of eight focus groups: Silver Lake (3), Harbour Pointe (2), Snohomish (2) and float pool (1). Seventeen prescribers, and 52 nurses and medical assistants participated. The ten major themes that emerged from the analysis were categorized according to the theoretical framework, developed *a priori*. An important and unexpected finding was that physicians realized they could now prescribe remotely – from home in the evenings. Secondary themes from the theoretical model were also mentioned. One important finding was that end-users stated that patients liked having the computer in the examination room, and enjoyed viewing their data with their physician. These are summarized in Table 2.

Aim 1c: Survey Study. 121 surveys were completed and returned – 63 for prescribers and 58 for staff. We are currently analyzing these.

Table 2: Focus group results: themes related to use of the e-prescribing system

Theme	Description
Individual level variables	Past experiences with computers influenced perceptions
Organizational level variable: Leadership	Important – training, feedback and support
Design level variable: Features, desired	Clinical decision support alerts and ‘favorites’ lists
Perceptions and Experiences: Benefits	Accuracy, transparency, integration
Perceptions and Experiences: Downsides	Programming errors; lack of wireless reliability
Perceptions and Experiences: Efficiency	Increased after the training period
Perceptions and Experiences: Expectations	Streamlined work
Perceptions and Experiences: Fears	At the paper-based clinic: fears present prior to implementation of e-prescribing; disappeared after implementation
Perceptions and Experiences: Impact	Prescribing from home – an unanticipated benefit
Perceptions and Experiences: Impressions	“I love it!”
Perceptions and Experiences: Safety, medication	Reduction in medication errors; improved tracking of controlled substances

Aim 2. Evaluate the Impact of the e-Prescribing System on Medication Safety, Specifically, Medication Errors and Adverse Drug Events.

Aim 2a. Compare the Epidemiology of Prescribing Errors (Characteristics and Severity), Comparing Those That Occurred Pre- to Post-Implementation. We reviewed 5,000 hand-written prescriptions written prior to e-prescribing implementation and 5,000 electronically written prescriptions written post-e-prescribing implementation. To date, we have published a manuscript that describes the characteristics of 1,500 pre-implementation errors in one internal medicine clinic that served as our pilot site²¹.

To date, we have also conducted a preliminary analysis of the pilot portion of this study – the 3,000 prescriptions written at the one internal medicine clinic that was the first at which the e-prescribing system was implemented. At this clinic, there was a 66% reduction in potential and actual medication errors, from 27.4% to 9.3% (Figure 4a). The majority of errors were potential errors only (25.1% pre- and 6.9% post-implementation: Level A, circumstances that can cause an error). The proportions of errors that did not cause harm (2.2% / 2.3%; Levels B-D, potential ADEs) and the proportion of errors that did cause harm (0.1% / 0.1%; Level E, preventable ADE) were low (Figure 4b), and were not affected by implementation of the basic e-prescribing system.

Figure 4a. Proportion of prescriptions with potential and actual medication errors

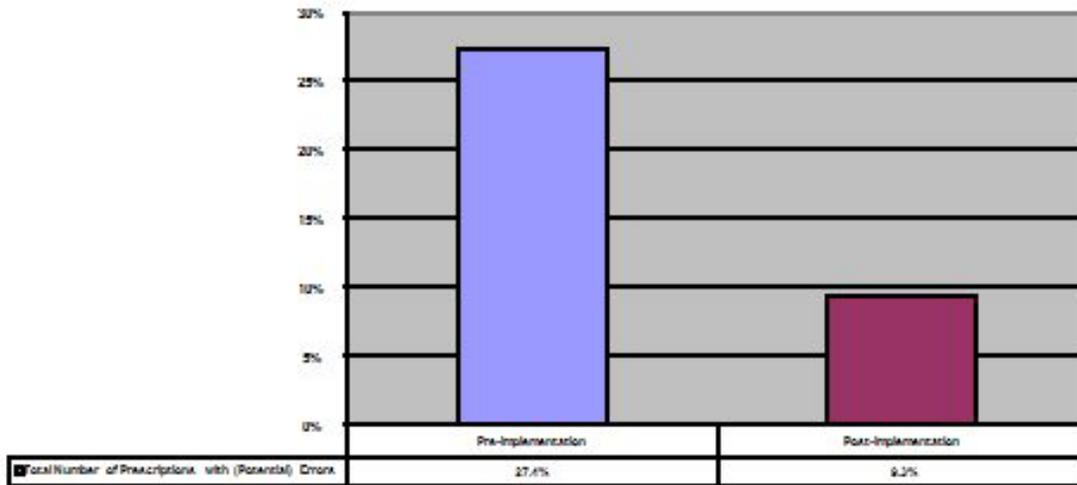
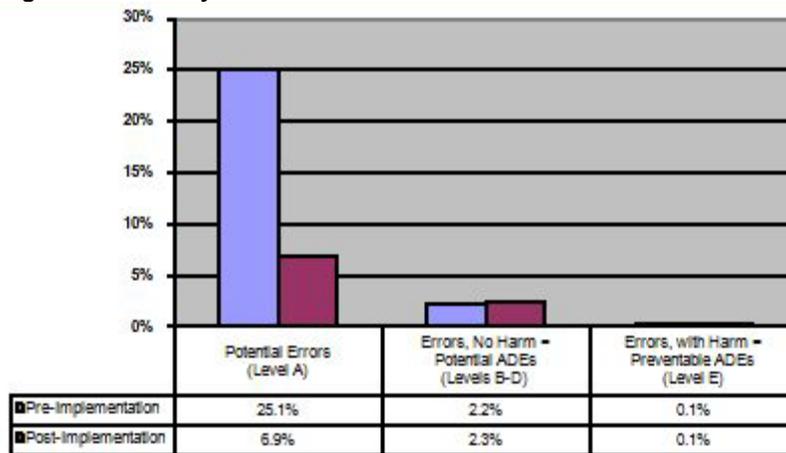
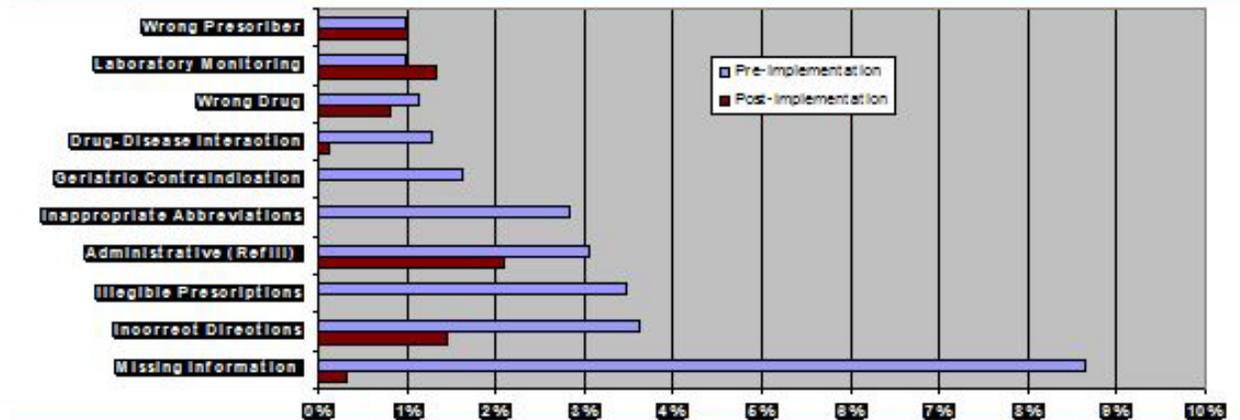


Figure 4b. Severity of medication errors



The characteristics that occurred with a frequency of greater than 1% are illustrated in Figure 4c. The most frequently occurring error characteristic was missing information, followed by incorrect directions and illegibility. Interestingly, drugs known to be contraindicated in geriatric patients (Beers criteria)²², drugs-disease interactions, and drugs that required laboratory monitoring occurred with a greater frequency than drug allergies or drug-drug interactions (the latter two occurred with a frequency < 1% are therefore not shown).

Figure 4c. Characteristics of medication errors



We are presently analyzing the full dataset of 10,000 prescriptions.

Aim 2b: Investigate the Relationship Between Medication Errors Identified in Aim 2a, and Downstream Adverse Drug Events (ADEs). Our query that matched prescriptions reviewed to inpatient and emergency department admissions returned 135 medications for 59 patients. Of these, 29 medications matched to 16 patients met our inclusion criteria for plausibility of the admission being associated with the medication prescribed. Thus, at this juncture, 0.29% of prescriptions (29 in 10,000 prescriptions) are being reviewed for their

association with a potential or preventable ADE. We are presently reviewing the charts of these 16 patients.

Discussion

Aim 1a: Describe the Steps Taken, Strategies Used and Lessons Learned that Enabled Successful Implementation. The lessons learned by The Everett Clinic during their e-prescribing implementation are consistent with those that appear in the literature. Our manuscript²⁰ is one of the first to document these lessons in the ambulatory setting. Thirteen years ago Sittig and Stead published a list of key ingredients that is still useful today to ensure successful implementation of a CPOE system.²³ They mention that the system must be fast and easy to use; that institutional commitment must be broad; and that it must come from the highest levels of the organization. More recently, the California Healthcare Foundation published reports that summarize successful strategies learned from CPOE implementation in community hospitals²⁴, and from electronic medical record implementation in small physician practices²⁵. These include executive vision and leadership, a collaborative environment, sufficient resources, and a strong IT program. More recently, Ash²⁶ found that the organization of information (system integration); and that technical/ implementation (usability, time, training, support), organizational (collaboration, culture and power), and professional (adaptation to local preferences) issues are all important to successful CPOE implementation.

Aim 1b: Evaluate the Impact of the e-Prescribing System on Organizational Workload and Workflow Processes. Results of the cross-sectional time-motion study revealed that, at the two sites that had implemented e-prescribing, e-prescribing was not associated with an increase in combined writing and computing time for prescribers. E-prescribing took slightly longer than hand-writing, but the difference was not statistically significant (12 seconds). When extrapolated to one day, this might add 3-5 minutes to a prescriber's day. At the e-prescribing sites, we did find that nurses spent more time computing than writing (5.4 minutes / hour), but this may have been offset by time spent in other activities at the paper-based site (restocking examination rooms, looking for charts, unoccupied). For medical assistants, there was little difference in time spent on any tasks. These results suggest that e-prescribing does not greatly disrupt workflow, and that adjustments can be made in other task areas.

Our results are consistent with those of others, although few studies have been based in the ambulatory setting and none have focused solely on e-prescribing. A recent systematic review²⁷ identified twelve studies that compared the time-efficiency of paper-based versus EHR systems for physicians. Not all studies employed time-motion methods; some used work-sampling methods. Results varied widely, from a 22% reduction to a 328% increase in physician time, when using an EHR. Specifically, Keshavjee used a battery of metrics (e.g. time spent conducting chart pulls, writing in the chart, writing prescriptions; number of clinic visits daily), to determine the impact of EHR implementation on workload processes in the office setting and found that the time required for most administrative tasks decreased within six months of implementation.²⁸ Bates' group found the proportion of time spent writing orders increased from 2.1% before CPOE implementation, to 9.0% afterward ($p < 0.0001$), but that this difference was offset by less time spent talking to other physicians, less time looking for charts, and less time walking.²⁹ Overhage found time spent e-prescribing increased prescribing by 0.43 minutes per patient, but that over time it fell by 3.73 minutes per patient.⁸

Separately, our secondary metrics indicate that implementation has been successful. The steady increase in the proportion of prescribers electronically prescribing (to 85%), in the number of paper charts pulled per month (5-fold reduction), and in the number of pharmacies to which e-prescriptions are auto-faxed (over 500), all indicate the impact on workflow and that workflow has markedly changed with e-prescribing.

Aim 1c: Evaluate the Impact of the e-Prescribing System on the Human Factors Aspects of the Implementation. The results of the focus group study revealed that perceptions and experiences with the e-prescribing system are largely favorable. Those that were not, were not surprising, and reflected challenges that were encountered during implementation (e.g. lack of reliability of the wireless network). Importantly, workload and workflow changed, and efficiencies were created as prescribers remarked positively on their ability to e-prescribe from home. It is also important that fears were not realized, that patients found that having computers in the examination rooms useful, and that prescribers were unwilling to return to paper-based prescribing. The results of the focus group study largely reflect what is known about e-prescribing systems evaluated in other settings - that accuracy and medication safety should improve²; that efficiency should either increase or be, at least, time neutral²⁷; and that training, feedback and support from leadership are critical to success²⁶.

Aim 2. Evaluate the Impact of the e-Prescribing System on Medication Safety, Specifically, Medication Errors and Adverse Drug Events.

Aim 2a. Compare the Epidemiology of Prescribing Errors (Characteristics and Severity), Comparing Those That Occurred Pre- to Post-Implementation. When characterizing the pre-implementation error characteristics in our pilot data²¹, almost 28% of prescriptions evaluated contained one or more errors or potential errors; however 92% (25.1% / 27.4%) of these errors were not actual errors, but potential errors, wherein there were “circumstances with the capacity to cause an error” (NCC MERP Level A¹⁴). 6.9% of the errors reached the patient. By definition, these are the errors that have the potential to cause harm. However, only 0.2% did cause harm – for an error rate of 2 in 1,000 prescriptions written that contained an error.

A priori, we had posited that the error characteristics most likely to occur would be one categorized as a non-clinical error (illegibility) and two categorized as clinical errors (allergy and drug-drug interactions). Interestingly, illegibility ranked third in the list of non-clinical characteristics that caused an error, behind missing information and wrong directions. Surprisingly, errors involving Beers²² criteria, drug-disease interactions, and lack of appropriate laboratory monitoring occurred more frequently than did errors involving allergies or drug-drug interactions. We believe that it is the non-clinical errors that may be impacted by a basic electronic prescribing system (illegibility, missing information, wrong dose); while those we defined as clinical errors may be impacted only when more sophisticated levels of CDS programming are added. Informed with the knowledge from this study, The Everett Clinic has developed CDS programming that provide prescriber alerts for drug-disease interactions, and guidelines for appropriate laboratory monitoring to prevent harm.

Bates’ group has led the field in studying the impact of CPOE systems on medication errors in the inpatient setting.^{2,30,31} However, few studies have focused on the impact of ACPOE systems on medication errors in the ambulatory setting. Gandhi evaluated the effect of

computerized prescribing in the outpatient setting.³² Although this group found no differences in error rates between sites that did or did not use e-prescribing, they suggested that CDS alerts could have prevented 95% of the errors found. In a recent study assessing reasons for medications requiring clarification, comparing pre- to post-CPOE implementation in both a community and university hospital, Wess found that dose, route, and frequency clarifications were far more common than were drug-drug interaction or drug-allergy clarifications.³³ These results are consistent with the error characteristics we most frequently found, as those having to do with missing information or illegibility.

Aim 2b: Investigate the Relationship Between Medication Errors Identified in Aim 2a, and Downstream Adverse Drug Events (ADEs). At this juncture, we are evaluating 0.29% of prescriptions (29 in 10,000 prescriptions) in our dataset for their association with a potential or actual ADE. This proportion of errors that may have led to an ADE is very small. This too, is consistent with the work of others. In one of Bates' early studies that evaluated the proportion of medication errors that led to ADEs, he found that only 0.9% of errors caused ADEs.³⁴ Further, when evaluating 160 handwritten prescriptions in a community-based general medicine practice, Gandhi found that errors occurred in 34% (54/ 160), and that 14.8% (8/ 54) of these were potential ADEs.³⁵ The proportion of errors that result in either potential or actual ADEs will be smaller in our study, largely due to differences in data collection methods.

Aim 2b: Generalizability of Findings. We had postulated, *a priori*, that the findings from our work would be generalizable for several reasons. In retrospect, we confirm this notion. Many of the barriers and challenges identified by other organizations³⁶ currently implementing commercially developed CPOE systems have also been faced by The Everett Clinic. Common to all systems^{37,38} are the identification and specification of core functionalities; aligning these with current standards; conceptualization of the impact of the system on workflow patterns and end-users; conducting a market analysis, comparing the costs and features of available systems, and deciding to build internally; conducting field tests to ensure optimal productivity; creating interfaces among modules, ensuring a reliable network and system security; and providing ongoing maintenance. As we have seen, the lessons that The Everett Clinic has learned transcend the type of software and hardware utilized. The Everett Clinic's approach of combining a commercially available drug-database with in-house programming, may offer a viable alternative to health-systems seeking the best strategy to launch their own e-prescribing initiative. Finally, although our time-motion, focus group, and survey studies were conducted in primary care settings, the lessons learned were captured, and medication error and ADE studies conducted clinic-wide.

Conclusions

In summary, the results of our projects have revealed that the impact of the e-prescribing system has been overwhelmingly positive. The initial timeframe for system implementation and adoption was exceeded by almost three years – with an original date of October 2006. The Everett Clinic positioned itself for success. We captured these steps, strategies and lessons learned that enabled this successful adoption. Clinic leadership is visionary, stable and supportive. The culture is positive, upbeat, and team-oriented. The system was implemented in an iterative fashion, with identification and implementation of improvements on an ongoing

basis. Clinician involvement contributed to iterative improvement. Training was provided one-on-one and just-in-time. Workflow redesign was recognized as an essential component of implementation and was undertaken as a part of the process. Challenges were thought of as opportunities for improvement, rather than barriers to adoption. The Everett Clinic concludes that implementation is a journey, not a solution.

In the process, efficiencies have been gained. The e-prescribing system has been voluntarily adopted by 85% of prescribers, with prescriptions being auto-faxed to over 500 pharmacies. The number of paper charts pulled decreased 5-fold from 2003 to 2007 at the pilot site. The results of the cross-sectional time-motion study revealed that, for prescribers, e-prescribing is largely time-neutral, and that for staff, the increased time spent computing may be offset by decreases in time spent in other activities. We anticipate similar results from the longitudinal analysis. Results from the focus group study revealed that prescribers and staff alike are enthusiastic about the e-prescribing system. They feel that the system has improved efficiencies and medication safety. These perceptions further enable system adoption. Importantly, the pilot data from the medication error study revealed over a 60% reduction in medication errors, and that the majority of these were only potential errors, did not reach the patient, and did not cause harm. In the analysis of pilot data, only 0.2% of errors reached the patient and caused harm, that is, 1 prescription each, in the pre- and post-implementation datasets. Further, the harm caused by these two prescriptions resulted solely in temporary harm that required intervention to resolve. No permanent harm was caused. We anticipate the results of the full medication error and ADE studies will reveal similar results. With these results, The Everett Clinic can confidently move forward into the HIT arena, further adopting HIT tools that will increase efficiencies and improve patient care.

An important dynamic that has enabled the success of this project has been the collaboration within a team that was comprised of a non-profit and a for-profit entity. Each member of the team, from his/her perspective viewpoint, has been enthusiastic about the work. We have divided the roles so that each person is contributing in a way that optimizes their professional responsibilities and strengths. Two members of the team at UW, and two at The Everett Clinic, assumed primary project responsibility. The site project coordinators have been responsible for day to day implementation (JWN) and evaluation (EBD), respectively. Overseeing all decisions have been the two principal investigators, AWF and SDS. Together, these four investigators are responsible for completion of work and dissemination of results. At the close of this successful endeavor, this team is positioned and motivated to continue to study important questions related to the implementation of HIT in the ambulatory setting.

Significance and Implications

We have used several methods to assess the impact of implementation of an e-prescribing system on a battery of outcomes. Ours is one of the first projects to utilize a multi-faceted approach to study this impact in a community-based, multispecialty health system that is not affiliated with an academic medical center. Moreover, it is one of the first sets of evaluations to capture these findings from an ambulatory health-system that has implemented a “homegrown” EHR and e-prescribing system. Further, our work also represent practice sites that are geographically distinct from other studies published to date, and will broaden the body of literature in this area.

Specifically, our strategies used and lessons learned when implementing an e-prescribing system in a community-based, ambulatory setting of an integrated health-system are some of the first to be described (Aim 1a). Our time-motion study is one of the first to include not only prescribers, but also nurses and other staff whose job descriptions include managing prescriptions (Aim 1b). The effectiveness of EHRs, CPOE and e-prescribing systems is critically dependent upon the interrelationships between humans, the tools they use, and the environment in which they live and work, the human factors aspects. Many factors influence the use of computers, including personality, prior computer experience, attitudes, interest and enthusiasm.^{9,10} Analyzing these factors, and using them to assess successful implementation of an e-prescribing system is an area of research that is still in its infancy. (Aim 1c) Similarly, most studies that evaluate the impact of medication errors and ADEs have been conducted in the hospital setting. Not only is ours conducted in the ambulatory setting, but our dataset includes prescriptions that reflect prescribing patterns of both primary care and specialty physicians (Aims 2a and 2b). The results of our work provide evidence that implementing a e-prescribing system in the community-based, ambulatory setting can be achieved successfully, and can have a positive impact on clinic efficiency, on the end-users' workday, and on medication safety.

References

1. Wickens CD, Becker SEG, Liu Y, et al. *An Introduction to Human Factors Engineering, 2nd edition*. Upper Saddle River, NJ: Pearson; 2004
2. Bates DW, Leape LL, Cullen DJ, et al. Effect of computerized physician order entry and a team intervention on prevention of serious medication errors. *JAMA* 1998;280:1311-1316
3. Kohn LT, Corrigan JM, Donaldson MS, eds. *To Err Is Human: Building a Safer Health System*. Washington DC: Institute of Medicine/National Academy Press; 1999
4. Weingart SN, Toth M, Sands DZ, et al. Physicians' decisions to override computerized drug alerts in primary care. *Arch Intern Med* 2003;163:2625-2631
5. Cherry DK, Woodwell DA. National Ambulatory Medical Care Survey: 2000 Summary. National Center for Health Statistics, 2002.
6. Reason J. *Human Error*. Cambridge, England: Cambridge University Press; 1990.
7. Leape LL. Errors in medicine. *JAMA* 1994;272:1851-1857.
8. Overhage JM, Perkins S, Tierney WM, et al. Controlled trial of direct physician order entry: effects on physicians' time utilization in ambulatory primary care internal medicine practices. *J Am Med Inform Assoc* 2001;8:361-371.
9. Hollingworth W, Devine EB, Hansen RN, Lawless NM, et al. The impact of e-prescribing on prescriber and staff time in ambulatory care clinics: A time-motion study. *J Am Med Inform Assoc*. 2007;14:722-30
10. Dixon DR, Bradley BJ. Adoption of information technology enabled innovations by primary care physicians: model and questionnaire development. *Proc Annu Symp Comput App Med Care* 1994;631-5
11. Dixon DR. The behavioral side of information technology. *Int J Med Inform* 1999;56:117-23
12. Davis FD, Bagozzi RP, Warshaw PR. User acceptance of computer technology: A comparison of two theoretical models. *Management Science* 1989;35(8):982-1001
13. Davis FD. Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Q* 1989;September:318-40
14. National Coordinating Council for Medication Error and Reporting and Prevention. Available from URL:<http://www.nccmerp.org/aboutMedErrors.html>. Accessed 11/9/07.

15. Devine, EB, Wilson-Norton JL, Lawless NM, et al. Preparing for ambulatory computerized prescriber order entry by evaluating preimplementation medication errors. In: Henriksen K, Battles JB, Marks ES, Lewin DI, eds. *Advances in patient safety: from research to implementation. Vol. 2, Concepts and methodology.* AHRQ Publication No. 05-0021-2. Rockville, MD: Agency for Healthcare Research and Quality; Feb 2005.
16. Morimoto T, Gandhi TK, Seger AC, et al. Adverse drug events and medication errors: detection and classification methods. *Qual Saf Health Care* 2004;13:306-314
17. Naranjo CA, Busto U, Sellers EM, et al. A method for estimating the probability of adverse drug reactions. *Clin Pharmacol Ther* 1981;30:239-45
18. US Department of Health and Human Services. MedWatch: The FDA Safety Information and Adverse Drug Event Reporting Program. Available from URL: <http://www.fda.gov/medwatch/SAFETY/3500.pdf>. Accessed: 11/15/07
19. Aspden P, Corrigan JM, Wolcott J, Erickson SM, eds. *Patient safety: Achieving a new standard for care.* Washington, DC: Institute of Medicine, 2003
20. Devine, EB, Wilson-Norton JL, Lawless NM, et al. Lessons learned when implementing an electronic health record in a community-based multispecialty clinic setting: A journey, not a solution. (submitted to the Agency for Healthcare Research and Quality, *Advances in Patient Safety: New Directions and Alternative Approaches.* September 2007)
21. Devine EB, Wilson-Norton JL, Lawless NM, et al. Characterization of prescribing errors in an internal medicine clinic. *Am J Health-Syst Pharm* 2007;64: 1062-70
22. Fick DM, Cooper JW, Wade WE, et al. Updating the Beers criteria for potentially inappropriate medication use in older adults: Results of a US consensus panel of experts. *Arch Intern Med* 2003 Dec8-22;163(22): 2716-24
23. Sittig DF, Stead WW. Computer-based physician order entry: the state of the art. *J Am Med Inform Assoc* 1994;1:108-123
24. Metzger J and Fortin J. *Computerized physician order entry in community hospitals: lessons from the field.* The California HealthCare Foundation and First Consulting Group. June 2003
25. Miller RH, Sim I, Newman J. *Electronic medical records: lessons learned from small physician practices.* The California HealthCare Foundation. October 2003.
26. Ash JS, Gorman PN, Lavelle M, et al. A cross-site qualitative study of physician order entry. *J Am Med Inform Assoc.* 2003;10:188-200
27. Poissant L, Pereira J, Tamblyn R, et al. The impact of electronic health records on time efficiency of physicians and nurses: A systematic review. *J Am Med Inform Assoc* 2005;12:505-16
28. Keshavejee K, Troyan S, Holbrook AMM, et al., for the COMPETE Investigators. Measuring the success of electronic medical record implementation using electronic and survey data. *Proc AMIA Symp.* 2001;;309-313
29. Bates DW, Shu K, Narasimhan D, et al. Comparing time spent writing orders on paper and physician computer order entry. *Proc AMIA Annu Symp* 2000:965
30. Bates DW, Leape LL, Petrycki S. Incidence and preventability of adverse drug events in hospitalized adults. *J Gen Intern Med* 1993;8:289-294.
31. Bates DW, Teich JM, Lee J, et al. The impact of computerized physician order entry on medication error prevention. *J Am Med Inform Assoc* 1999; 6:313-321.
32. Gandhi TK, Weingart SN, Seger AC, et al. Outpatient prescribing errors and the impact of computerized prescribing. *J Gen Intern Med* 2005;20:837-41
33. Wess ML, Embi PJ, Besier JL, et al. Effect of a computerized provider order entry (CPOE) system on medication orders at a community hospital and university hospital. *Proc Am Med Inform Assoc* 2007;796-800
34. Bates DW, Boyle DL, Vander Vliet MB, et al. Relationship between medication errors and adverse drug events. *J Gen Intern Med.* 1995;10:199-205
35. Gandhi TK, Weingart SN, Leape LL, et al. Medication errors and potential adverse drug events among outpatients (abstract). *J Gen Intern Med.* 2000;15(suppl 1):116
36. Poon EG, Blumenthal D, Jaggi T, et al. Overcoming barriers to adopting and implementing computerized physician order entry systems in U.S. hospitals. *Health Affairs* 2004;23(4):185-90

37. Bell DS, Marken RS, Meili RC, et al. Recommendations for comparing electronic prescribing systems: results of an expert consensus process. *Health Aff* May 25, 2004. W4-305-W4-317

38. Bell DS, Cretin S, Marken RS, et al. A conceptual framework for evaluating outpatient electronic prescribing systems based on their functional capabilities. *J Am Med Inform Assoc* 2004;11:60-70

List of Publications and Products

Publications

1. Hollingworth W, Devine EB, Hansen RN, et al. The impact of e-prescribing on prescriber and staff time in ambulatory care clinics: A time-motion study. *J Am Med Inform Assoc*. 2007;14:722-30

2. Devine EB, Wilson-Norton JL, Lawless NM, et al. Characterization of prescribing errors in an internal medicine clinic. *Am J Health-Syst Pharm* 2007;64: 1062-70

3. Devine, EB, Wilson-Norton JL, Lawless NM, et al. Preparing for ambulatory computerized prescriber order entry by evaluating preimplementation medication errors. In: Henriksen K, Battles JB, Marks ES, Lewin DI, eds. *Advances in patient safety: from research to implementation. Vol. 2, Concepts and methodology*. AHRQ P No. 05-0021-2. Rockville, MD: Agency for Healthcare Research and Quality; Feb '05.

Manuscripts Submitted

Devine, EB, Wilson-Norton JL, Lawless NM, et al. Lessons learned when implementing an electronic health record in a community-based multispecialty clinic setting: A journey, not a solution. (submitted to the Agency for Healthcare Research and Quality, *Advances in Patient Safety: New Directions and Alternative Approaches*. September 2007)

Manuscripts in Preparation

1. Devine EB, Dixon D, Lawless NM, Wilson-Norton JL, et al. End-users experience with an ambulatory electronic prescribing system. (intended for *J Am Med Inform Assoc*)

2. Devine EB, Hansen RN, Wilson-Norton JL, Lawless NM, et al. Evaluating the impact of an ambulatory electronic prescribing system on medication safety. (intended for *J Am Med Inform Assoc*)

3. Devine EB, Hollingworth W, Hansen RN, Lawless NM, Wilson-Norton JL, et al. Evaluating the impact of an ambulatory electronic prescribing system on clinic workflow. (intended for *J Am Med Inform Assoc*)

4. Devine EB, Lawless NM, Wilson-Norton JL, et al. End-users perceptions of an ambulatory electronic prescribing system. (intended for *J Am Med Inform Assoc*)

Presentations – National

1. Devine EB, Wilson-Norton JL, Lawless NL, et al. Implementing an ambulatory e-prescribing system: A journey, not a solution. First Annual Meeting of the Agency for Healthcare Research and Quality. Washington DC, September 2007 (podium)

2. Devine EB, Wilson-Norton JL, Lawless NL, et al. End-users perceptions of an ambulatory electronic prescribing system. First Annual Meeting of the Agency for Healthcare Research and Quality.

Washington DC, September 2007 (poster)

3. Hollingworth W, Devine EB, Hansen RN, et al. The impact of an ambulatory electronic prescribing system on prescriber and staff time: A time-motion study. AHRQ Annual Patient Safety and Health Information Technology Conference. Agency for Healthcare Research and Quality. Washington DC, June 2006 (podium)

4. Devine EB, Wilson-Norton JL, Lawless NM, et al. Characterizing the Epidemiology of Medication Errors in a Multispecialty Clinic Setting. American Society of Health-System Pharmacists Midyear Clinical Meeting, Las Vegas, NV, December 2005. (podium)
5. Devine EB, Wilson-Norton JL, Lawless NM, et al. Evaluating prescribing errors pre- and post-CPOE in the ambulatory setting. 2005 Annual Patient Safety and Health Information Technology Conference: Making the Health Care System Safer through Implementation and Innovation. Agency for Healthcare Research and Quality. Washington DC. June 2005 (podium)
6. Hollingworth W, Lawless NM, Devine EB, et al. Evaluating the Impact of an ACPOE/CDS System on Outcomes: Using a Time and Motion Study to Measure Workload. 2005 Annual Patient Safety and Health Information Technology Conference: Making the Health Care System Safer through Implementation and Innovation. Agency for Healthcare Research and Quality. Washington DC. June, 2005 (exhibit display)
7. Devine EB. Keys to Successful ACPOE Implementation. Clinical Pearl Presentation. American Society of Health-System Pharmacists Midyear Clinical Meeting. Orlando, FL. December 2004 (podium)
8. Devine EB, Wilson-Norton JL, Lawless NM, et al. Evaluating the Impact of an ACPOE System on Process Outcomes in the Multispecialty Clinic Setting. 2004 Patient Safety Congress of the National Patient Safety Foundation. Boston, MA, May 2004. (poster)
9. Te S, Wong C, Devine EB, Wilson-Norton JL, Lawless NM, et al. Characterizing the epidemiology of medication errors pre-implementation of an ACPOE system. ASHP Midyear Clinical Meeting. New Orleans, LA, December 2003. (poster)
10. Wilson-Norton JL, Lawless NM, Fisk AF, Rafoth RJ. The use of electronic prescribing technology to impact medication errors. Final project presentation to the members of the Safety Collaborative in the Outpatient Environment (SCOPE) project. American Medical Group Association. New Orleans, LA, November 2003. (podium)

Presentations – Regional and Local

1. Devine EB. Implementing and Evaluating an Ambulatory e-Prescribing System: A Journey, Not a Solution. University of Washington K-12 Clinical Scholars Seminar, Seattle, WA (October 2007)
2. Devine EB. The Intersection of Medication Safety and Human Factors. Washington State Board of Pharmacy, Kent, WA (October 2007)
3. Devine EB. The Intersection of Medication Safety and Human Factors. Washington State Board of Pharmacy, Dispensing Error Sanctioning Committee, Seattle, WA (September 2007)
4. Devine EB. Improving Quality and Safety in the Medication Use Process: The Pharmacist's Role on the Team. Northwest Regional Primary Care Association, Spring 2007 Primary Care Conference, Portland, OR (May 2007)
5. Devine EB. The Impact of Technology on Quality and Patient Safety: A Barrier or a Solution? Pharmacy Grand Rounds, University of Washington, School of Pharmacy, Seattle, WA (April 2007)
6. Hansen R, Ferrera T, Lawless NL. e-Prescribing at The Everett Clinic: The Retail Pharmacy Experience. 2006 Northwest Pharmacy Convention, Coeur d'Alene, ID (June 2006)
7. Wilson-Norton JL, Devine EB. Implementing CPOE in the Ambulatory Setting – The Everett Clinic. Presented to Premera, Mountlake Terrace, WA (September 2005)
8. Devine EB, Wilson-Norton JL. Implementing CPOE in the Ambulatory Setting – The Everett Clinic. Third Pharmaceutical Quality Improvement Conference. Pharmaceutical Outcomes Research & Policy Program, University of Washington. Seattle, WA (June 2005)
9. Fisk AW, Wilson-Norton JL, Devine EB. The Everett Clinic's Perspective on Electronic Prescribing Narcotic Verification. Washington State Board of Pharmacy, Kent, WA. (April 2005)
10. Devine EB. Medication Safety Research: Characterizing the Problem/Evaluating a Solution. Presentation to the University of Washington, Corporate Advisory Board. Seattle, WA (Oct 2003)
11. Devine EB, Wilson-Norton JL. Quality Improvement and Patient Safety in a Medical Group, Pharmaceutical Quality Initiatives Conference. Pharmaceutical Outcomes Research & Policy Program, University of Washington, Seattle, WA (February 2003)

Solicited Interviews

1. Wilson-Norton JL, Devine EB. Clinic Launches New e-Prescribing System. AHRQ 411 Podcast. September 26, 2007. <http://healthcare411.ahrq.gov:80/podcast.aspx?id=271>. Accessed November 16, 2007
2. Pizzi R. CPOE and Patient Safety. Healthcare IT News. September 2007
<http://www.healthcareitnews.com:80/story.cms?id=7678>. Accessed November 16, 2007 (EB Devine, interviewee)
3. Devine EB, Wilson-Norton JL. Quality Metrics in the Context of HIT Implementation and Evaluation. An interview conducted by the Center for Information Technology Leadership. August 2007 (no report available)
4. Devine EB, Wilson-Norton JL. Quality Metrics in the Context of HIT Implementation and Evaluation. An interview conducted by the AHRQ National Resource Center. July 2007. (report forthcoming from the NRC)

Lay Press

1. Dash H and Fisk A. A prescription for improving medication safety. (The Everett) HeraldNet. August 5, 2006. Available from URL:
<http://www.heraldnet.com/stories/SWPrintIT.cfm?page=http%3A%2F%2Fwww%2Eheraldnet>. (archived)
2. Electronic prescribing at The Everett Clinic. The Everett Clinic Connection. Autumn 2005. page 1
3. Ludington J. Grant enables UW School of Pharmacy to evaluate computer-prescribing technology. The Daily, of the University of Washington. November 29, 2004 page 1
4. Mandt L. Everett Clinic uses grant to reduce prescription mistakes. The Everett Tribune. November 24, 2004. page 6
5. HHS awards grant to study computerized prescribing. iHealthBeat. November 19, 2004. Available from URL:
<http://www.ihealthbeat.org/index.cfm?Action=dspItem&itemID=I07521> (archived)
6. School of Pharmacy and Everett Clinic test computerized prescribing. University Week, University of Washington. November 18, 2004. Page 14
7. Salyer S. Clinic pioneers new Rx system. (The Everett) HeraldNet. November 17, 2004 Available from URL:
<http://www.heraldnet.com/stories/SWPrintIt.cfm?page=http%3A%2F%2Fwww%2Eheraldnet>. (archived)
8. Schwarzen C. Clinic, school receive federal grant. The Seattle Times. November 17, 2004. page B2
9. HHS awards grant to study computerized prescribing.

Awards

1. In recognition of the e-prescribing initiative in improving patient safety, The Everett Clinic received the William O. Robertson Patient Safety Award, awarded by the Washington State Medical Association. October 2005
2. In recognition for its initiative in process redesign and adoption of clinical outcomes metrics to align the Clinic with the Six IOM Aims for Improving Patient Care, The Everett Clinic received the “Acclaim” Award, awarded by the American Medical Group Association, September 2007