Evaluating the Impact of an Ambulatory Computerized Provider Order Entry System on Outcomes in a Community-based, Multispecialty Health System

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MEBI 590 Seminar
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1997 Institute of Medicine Report
Electronic Health Records (EHRs)

- Improve quality and safety
- Enhance the productivity of health care professionals; reduce administrative costs
- Support clinical and health services research
- Ensure patient data confidentiality at all times
- Accommodate future developments
CPOE systems*:
A core component of EHRs

**Basic**
- Computer entry of prescription information
  - Drug, dosage form, route
  - Directions
  - Quantity
  - Patient name
  - Date
  - Prescriber’s signature
  - Duplicate therapy
  - Allergies
  - Drug-drug interactions
  - Formulary checking

**Advanced**
- Drug-disease interactions
- Laboratory checking
- Dose calculators
- Medication selection aids
- Preventive monitoring

* CPOE=Computerized provider order entry
CDS = Clinical Decision Support

Kuperman. JAMA 2007;14:29-40
2004 Congressional Mandate

Agency for Healthcare Research and Quality

Health Information Technology Grant
5 UC1 HS 015319-03 (Sullivan)

Mentored Clinical Scientist Training Grant:
K08 HS 014739-02A2 (Devine)

Our Partnership:

UNIVERSITY OF WASHINGTON

The Everett Clinic
For the whole you.
Three Aims; Three Studies (1)

• **Aim (Study) #1 – Medication Error Study**
  - **Aim 1a:** Evaluate the impact of the CPOE system on medication errors, comparing pre-to post-
    - **Aim 1a1:** the distribution of errors
    - **Aim 1a2:** epidemiology of error characteristics
    - **Aim 1a3:** the distribution of error severity
  
  - **Aim 1b:** Link errors to subsequent adverse drug events (ADEs)
Three Aims; Three Studies (2)

• **Aim (Study) #2 – Time-Motion Study**
  - Evaluate the impact of the CPOE system on time-intensity of prescribing, and on work tasks
    • Time spent handwriting *versus* e-prescribing
    • Time spent e-prescribing using an interim hardware configuration (phase 1) *versus* the final hardware configuration (phase 2)
    • Time spent on work tasks
    • Time spent on overall activity types
Aim (Study) #3 – Focus Group Study
- Explore and describe end-users’ perceptions of and experiences with the CPOE system
- Map results to the information technology adoption model
The Everett Clinic

- Physician owned and managed multi-specialty integrated health-system with a 79-year history
- 14 locations; 60 clinics - ambulatory oncology and behavioral health
- Ancillary services - laboratory, radiology
- 225 physician-owners / 1,250+ employees
- 225,000 patients; 610,000 ambulatory visits annually
- 4 on-site pharmacies; 2.7 million prescriptions annually
- Admit to single hospital in local market
- Core values
  - We do what is right for each patient
  - We provide an enriching and supportive workplace
  - Our team focuses on value: service, quality and cost
The Everett Clinic’s CPOE Software

- Clinitech® - Information Technology subsidiary
- Internal development of EHR began in 1995
  - chart notes, labs and imaging reports
- CPOE implemented in 2003 – limited to medications
- Utilizes a commercial drug database
- Features of the CPOE system (basic) – medications only
  - ability to write new prescriptions (output: fax/print)
  - ability to refill prescriptions
  - optimizes ideal choice of medication
  - automatically generates medication list as prescriptions are written
  - calculates pediatric antibiotic dosing by weight
- Builds patient drug database, improving disease management
Study #1: Medication Error Study: Hypotheses

- **Aim 1a**: Evaluate the impact of the CPOE system on medication errors, comparing pre- to post-
  - **1a1**: 50% reduction in the distribution (frequency) of errors
  - **1a2**: Types of errors will change
    - Reduction in errors most logically impacted by a basic CPOE system
  - **1a3**: Reduction in errors of all severity levels

- **Aim 1b**: Link errors to ADEs
  - Exploratory analysis
Medication Errors

Potential ADEs

Preventable (ADEs)

Not Preventable (ADRs)

Background (1) - History

- Drug complications constitute 19% of total adverse events\(^1\)
- Medication errors occur in 5.3% of inpatient orders; 7.5% of these can result in an adverse drug event\(^2\)
- CPOE with CDS alerts resulted in a 55%\(^3\) and 81%\(^4\) reduction in medication errors
- 44,000 – 98,000 deaths per year occur as result of medical errors in hospitals\(^5\)
- IOM - *Preventing Medication Errors, 2006*

\(^1\)Leape, NEJM 1991;324:377-84; \(^2\)Bates, JGI M 1995;10:199-205; \\
\(^5\)I nstitute of Medicine. 1999
Background (2) – State of the Field

• Systematic reviews\textsuperscript{1-6} investigating the impact of CPOE/ CDS systems on medication safety:
  • inpatient setting, academic medical centers
  • “homegrown” systems
  • Wide variety in design, quality and results
  • Few focus on ADEs; some focus on CDS alerts
• Great potential for errors in the ambulatory setting
  • One (academic, major institution, “homegrown”)\textsuperscript{7}
  • 4 primary care practices – 2 handwritten, 2 CPOE
  • 1,879 prescriptions
  • 7.6% contained an error; 43% were potential ADEs; 3 errors caused ADEs
  • CDS could have prevented 95% of potential ADEs

\textsuperscript{1}Kaushal, Arch Intern Med 2003; \textsuperscript{2}Garg JAMA 2005; \textsuperscript{3}Eslami J AMIA 2007; \textsuperscript{4}Shamnliyan HSR 2008; \textsuperscript{5}Wolfstadt J Gl M 2008; \textsuperscript{6}Ammenwerth J AMIA 2008; \textsuperscript{7}Gandhi, J Gl M 2005
Methods (1)

• Quasi-experimental, pre,- post- design
• Retrospective review of 5,000 prescriptions in each of two time frames (2 reviewers)
• Filled at one of three onsite pharmacies
• Weighted sampling
• Variables:
  – Primary outcome: error – yes/no
  – Secondary outcomes: characteristics (13) and severity (3-levels)
  – Primary independent variable: CPOE – yes/no
  – Data sources: prescriptions, EHR, laboratory values
  – Covariates: patient age & gender, prescriber specialty, therapeutic drug class, season, weeks since 1st Rx written
  – Interaction terms: CPOE and each covariate
• Approved by the UW Human Subjects Committee
Methods (2) – Analyses

• Unadjusted – two-sample test of proportion for each outcome

• Hierarchical data – prescription, prescriber, geographic site

• Distribution & characteristics – binary outcomes
  • GEE with alternating logistic regression (ALR)\(^1\)
  • Clustered on prescriber and geographic site
  • \(\alpha\) for geographic site NS, so included as fixed effect
  • First order GEE, clustering on prescriber
  • Weight variable to reflect clinic prescribing patterns
  • Created best fitting model, retaining variables (or groups) with \(p<0.05\)

• Error severity
  • Collapsed 6-levels to 3
  • Generalized linear & latent mixed effects model (GLLAMM)\(^2\)
  • Multinomial logit link; same covariates

\(^1\)Carey. Biometrika 1993;80:517-26; \(^2\)Rabe-Hesketh & Skrondal 2008
### Table 1.1: Characteristics of Patients and Prescriptions

<table>
<thead>
<tr>
<th></th>
<th>Pre-CPOE (N=5,016)</th>
<th></th>
<th>Post-CPOE (N=5,153)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Patient age (≥ 65 years)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>597 (11.9%)</td>
<td></td>
<td>729 (14.2%)§</td>
<td></td>
</tr>
<tr>
<td><strong>Female</strong></td>
<td>2,887 (57.6%)</td>
<td></td>
<td>3,086 (59.9%)*</td>
<td></td>
</tr>
<tr>
<td><strong>Prescriber specialty</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal Medicine</td>
<td>1,843 (36.7%)</td>
<td></td>
<td>2,347 (45.6%)§</td>
<td></td>
</tr>
<tr>
<td>Family Practice</td>
<td>1,255 (25.0%)</td>
<td></td>
<td>1,296 (25.2%)</td>
<td></td>
</tr>
<tr>
<td>Pediatrics</td>
<td>492 (9.8%)</td>
<td></td>
<td>407 (7.9%)§</td>
<td></td>
</tr>
<tr>
<td>Walk-in Clinic</td>
<td>475 (9.5%)</td>
<td></td>
<td>345 (6.7%)§</td>
<td></td>
</tr>
<tr>
<td>Specialty</td>
<td>836 (16.7%)</td>
<td></td>
<td>646 (12.5%)§</td>
<td></td>
</tr>
<tr>
<td>All others</td>
<td>115 (2.3%)</td>
<td></td>
<td>112 (2.2%)</td>
<td></td>
</tr>
<tr>
<td><strong>Therapeutic drug class</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Antibiotics</td>
<td>1,180 (23.5%)</td>
<td></td>
<td>746 (14.5%)§</td>
<td></td>
</tr>
<tr>
<td>Antidepressants</td>
<td>257 (5.1%)</td>
<td></td>
<td>296 (5.7%)</td>
<td></td>
</tr>
<tr>
<td>Central Nervous System Agents</td>
<td>402 (8.0%)</td>
<td></td>
<td>568 (11.0%)§</td>
<td></td>
</tr>
<tr>
<td>Hormones</td>
<td>278 (5.5%)</td>
<td></td>
<td>370 (7.2%)§</td>
<td></td>
</tr>
<tr>
<td>Schedule II-V</td>
<td>1,004 (20.0%)</td>
<td></td>
<td>960 (18.6%)</td>
<td></td>
</tr>
<tr>
<td>All others</td>
<td>1,895 (37.8%)</td>
<td></td>
<td>2,213 (43.0%)§</td>
<td></td>
</tr>
<tr>
<td><strong>Geographic site</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clinic site A</td>
<td>1,420 (28.3%)</td>
<td></td>
<td>1,691 (32.8%)§</td>
<td></td>
</tr>
<tr>
<td>Clinic site B</td>
<td>1,741 (34.7%)</td>
<td></td>
<td>2,053 (39.8%)§</td>
<td></td>
</tr>
<tr>
<td>Clinic site C</td>
<td>1,450 (28.9%)</td>
<td></td>
<td>1,087 (21.1%)§</td>
<td></td>
</tr>
<tr>
<td>All other clinic sites</td>
<td>405 (8.1%)</td>
<td></td>
<td>322 (6.3%)§</td>
<td></td>
</tr>
</tbody>
</table>

CPOE = computerized provider order entry  
*p<0.05; †p<0.01; ‡p<0.005; §p<0.001 when compared to pre-CPOE
## Results (2)

### Table 1.2: Impact of the CPOE system on medication errors

<table>
<thead>
<tr>
<th></th>
<th>Pre-CPOE N (%)</th>
<th>Post-CPOE N (%)</th>
<th>Difference N (%); 95% CI for Difference (Unadjusted)</th>
<th>Odds Ratio 95% CI (Adjusted)*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total number of prescriptions reviewed</strong></td>
<td>5,016 (49.3%)</td>
<td>5,153 (50.7%)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total number of prescriptions with one or more errors</strong></td>
<td>911 (18.2%)</td>
<td>423 (8.2%)</td>
<td>488 ((10.0%) (8.7%, 11.3%))</td>
<td>0.30 (0.23, 0.40)</td>
</tr>
<tr>
<td><strong>Total number of errors</strong></td>
<td>1,012</td>
<td>440</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Number of errors per prescription</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One</td>
<td>811</td>
<td>405</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Two</td>
<td>85</td>
<td>16</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Three</td>
<td>9</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Four</td>
<td>1</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Mean number of errors per prescription</strong></td>
<td>1.09</td>
<td>1.04</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

CI = confidence interval; CPOE = computerized provider order entry

*Generalized estimating equations with independent correlation; clustering at the prescriber level; prescription weighting schema applied

Adjusted model contains the following variables: Main effects: age (< ≥65), gender, antibiotics, antidepressants, central nervous system (CNS) agents, hormones, Schedule II-V agents, clinic site A, clinic site B, clinic site C;
Interaction terms: CPOE*CNS agents, CPOE*hormones, CPOE*Schedule II-V, CPOE*site C
Results – Error Characteristics (3)

- **Inappropriate abbreviations**
- **Information missing**
- **Illegibility**
- Wrong directions
- Inappropriate lab monitoring
- *Drug-disease interaction*
- Contraindication in ≥65yo
- **Drug-drug interaction**
- *Wrong strength*
- All other types
- Wrong drug
- Wrong dose
- Therapeutic duplication

![Graph showing proportion of prescriptions with errors](image)

* p<0.005
** p<0.001

Proportion of prescriptions with errors

- **Pre-CPOE**
- **Post_CPOE**
Results – Error severity (4)

14 / 10,169 (0.1%) of prescriptions included an error that caused harm

1 level “F” error (caused harm; required hospitalization); occurred pre-CPOE

Lab monitoring (4), drug-disease interactions (3), wrong directions (3), wrong dose (2)

No association found between errors and subsequent ADEs

Table 1.3: Effect of the CPOE system on medication errors, by severity

<table>
<thead>
<tr>
<th>Error Severity</th>
<th>Total prescriptions Pre-CPOE N=5,016</th>
<th>Total prescriptions Post-CPOE N=5,153</th>
<th>Difference N (%)</th>
<th>Odds Ratio (99.5% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>95% CI for Difference (Unadjusted)</td>
<td>Adjusted</td>
</tr>
<tr>
<td>A (potential error; no ADE) N=8</td>
<td>7 (0.1%)</td>
<td>1 (&lt;0.1%)</td>
<td>5 (&lt;0.1%)</td>
<td>0.13 (0.02, 1.07)</td>
</tr>
<tr>
<td>B-D (error, no harm; potential ADE) N=1,312</td>
<td>895 (17.8%)</td>
<td>417 (8.1%)</td>
<td>478 (9.8%)</td>
<td>0.43 (0.38, 0.49)</td>
</tr>
<tr>
<td>E &amp; F (error, reached patient-contributed to harm; preventable ADE) N=14</td>
<td>9 (0.2%)</td>
<td>5 (0.1%)</td>
<td>4 (&lt;0.1%)</td>
<td>0.51 (0.17, 1.53)</td>
</tr>
</tbody>
</table>

ADE = adverse drug event; CI = confidence interval; CPOE = computerized provider order entry

*p<0.05; †p<0.01; ‡p<0.005; §p<0.001

GLLAMM with adaptive quadrature; multinomial logit model; clustering at prescriber level; no weights applied; no additional variables
Notable Findings

• 55% reduction in frequency of errors with CPOE system
  – 70% reduction in odds of an error occurring (OR: 0.3); 95% CI 0.23, 0.40)

• Reductions in most types of errors
  – Greatest reduction in errors impacted by a basic CPOE system

• Most errors do not cause harm (potential ADEs)
  – 57% reduction in odds (OR: 0.43, 95% CI; 0.38, 0.49)
  – 0.1% of errors caused harm (preventable ADEs)
Strengths and Limitations

• Large dataset
• Two independent evaluators
• Rigor of analytic methods

• Retrospective methods preclude definitive evaluation of errors that cause harm
• Capture prescribing errors only
• Limited generalizability
  – “homegrown” system
  – community setting with specific prescribing patterns
  – three pharmacies
    • weighting scheme may address this
Study #2: Time-Motion Study

• **Aim 2.1**: Evaluate time spent (seconds) handwriting vs. e-prescribing (prescribers)
  
  • Hypothesis: The impact of e-prescribing will be time-neutral for prescribers

• **Aim 2.2**: Evaluate time spent (seconds) eprescribing, comparing phase 1 to phase 2 (prescribers)

• **Aim 2.3**: Evaluate time spent (min/hour) on work tasks, comparing phase 1 to phase 2 (prescribers & staff)

• **Aim 2.4**: Evaluate time spent (proportions) on overall activity categories, comparing phase 1 to phase 2 (prescribers & staff)
<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Setting</th>
<th>Methods</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tierney</td>
<td>1993</td>
<td>RCT of CPOE in urban hospital (n=68 teams)</td>
<td>Time-motion</td>
<td>+ 33 min/ 10 hour shift (p&lt;0.001); less time record-keeping</td>
</tr>
<tr>
<td>Shu</td>
<td>2001</td>
<td>Pre-, post-CPOE in inpatient setting</td>
<td>Work-sampling</td>
<td>Increase from 2.1% to 9.0%; (p&lt;0.001); less time charting; patient care time unchanged</td>
</tr>
<tr>
<td>Overhage</td>
<td>2001</td>
<td>RCT of CPOE at 11 clinics (n=34)</td>
<td>Time-motion</td>
<td>+ 0.43 min (NS); - 3.73 min</td>
</tr>
<tr>
<td>Pizziferri</td>
<td>2005</td>
<td>Pre-, post-EHR at 5 clinics (n=20)</td>
<td>Time-motion</td>
<td>- 30 secs/ patient; patient care time unchanged</td>
</tr>
<tr>
<td>Poissant</td>
<td>2005</td>
<td>Systematic review of CPOE and EHR</td>
<td>Several</td>
<td>- 28% to + 328%; 3/ 12 studies with time savings</td>
</tr>
</tbody>
</table>
Study Design

- Direct observation – One 4 hour time block per end-user
- All prescribers and staff whose job involves prescriptions
- With consent of prescriber and patient
- Approved by UW Human Subjects Committee

<table>
<thead>
<tr>
<th>Clinic</th>
<th>Phase 1</th>
<th>Phase 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silver Lake</td>
<td>Paper</td>
<td>Exam Room Desktop</td>
</tr>
<tr>
<td>Harbour Pointe</td>
<td>Prescriber Office Desktop</td>
<td>Exam Room Desktop</td>
</tr>
<tr>
<td>Snohomish</td>
<td>Wireless Laptop</td>
<td>Exam Room Desktop</td>
</tr>
</tbody>
</table>
## Data Elements (1)\(^1\)

<table>
<thead>
<tr>
<th>Major Task Categories (12)</th>
<th>Individual Categories (106)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1) Computer</strong></td>
<td>New Rx; Renew Rx; Fax Rx; (Drug Ref; e-mail; Lit Search; Look Up Data)</td>
</tr>
<tr>
<td><strong>2) Writing</strong></td>
<td>New Rx; Renew Rx; (Letter; Notes/Charts; Orders)</td>
</tr>
<tr>
<td><strong>3) Phone</strong></td>
<td>Rx; FAX Rx; Prior Authorization (Getting Results; Paging; Personal; Scheduling test)</td>
</tr>
</tbody>
</table>

### Other Major Task Categories

<table>
<thead>
<tr>
<th>4) Examine/ read</th>
<th>8) Phone patient</th>
</tr>
</thead>
<tbody>
<tr>
<td>5) Examine patient</td>
<td>9) Procedure</td>
</tr>
<tr>
<td>6) Looking for</td>
<td>10) Talking</td>
</tr>
<tr>
<td>7) Other</td>
<td>11) Talking Patient</td>
</tr>
</tbody>
</table>

\(^1\)Overhage, JAMIA 2001;361-71
## Data Elements (2)

### Overall Activity Types

<table>
<thead>
<tr>
<th>Direct patient care</th>
<th>Indirect patient care – other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indirect patient care – write</td>
<td>Administrative</td>
</tr>
<tr>
<td>Indirect patient care – read</td>
<td>Miscellaneous</td>
</tr>
</tbody>
</table>

1. Overhage, JAMIA 2001;361-71
Analyses (1)

- **Aim 2.1**: seconds to prescribe (event)
  - **Linear Mixed Model**
    - Outcome variable = adjusted mean difference in the number of seconds spent pre prescription-related event
    - Primary independent variable = handwritten (phase 1 or 2) vs. e-prescribed (phase 2)
    - Fixed effect covariates = new or refilled prescription, clinic, days exposed to software / hardware
    - Random effect = prescriber

- **Aim 2.2**: Same linear mixed model
  - Primary independent variable = e-prescribed (phase 1) vs. e-prescribed (phase 2)

- Unpaired analyses
Analyses (2)

- **Aim 2.3**
  - Unit of analysis = major task category
  - Outcome variable
    - Mean number minutes / hour on each task
    - Summed for each subject, by task
    - Weighted by total number of minutes observed
    - Average of all subjects, by task
  - Grouping variable
    - phase 1 or phase 2
  - Unpaired t-tests
  - Stratified by professional type & clinic

**Aim 2.4**: Overall activity types

- Two sample tests of proportions, by activity
### Table 2.1: Characteristics of Prescribers and Staff, and Time Observed

<table>
<thead>
<tr>
<th></th>
<th>Silver Lake</th>
<th></th>
<th>Harbour Pointe</th>
<th></th>
<th>Snohomish</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Phase 1</td>
<td>Phase 2</td>
<td>Phase 1</td>
<td>Phase 2</td>
<td>Phase 1</td>
<td>Phase 2</td>
</tr>
<tr>
<td><strong>Prescribers</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consented (%)</td>
<td>8/10 (80%)</td>
<td>13/14 (93%)</td>
<td>11/15 (73%)</td>
<td>16/16 (100%)</td>
<td>8/8 (100%)</td>
<td>9/9 (100%)</td>
</tr>
<tr>
<td>Specialty</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal medicine</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Family practice</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>6</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Pediatrics</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>5</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Walk-in clinic</td>
<td>2</td>
<td>4</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Mean hours observed</td>
<td>3.9</td>
<td>3.8</td>
<td>3.8</td>
<td>3.8</td>
<td>3.9</td>
<td>3.9</td>
</tr>
<tr>
<td>Mean number of minutes unable to observe</td>
<td>19.8</td>
<td>13.9</td>
<td>12.7</td>
<td>34.7</td>
<td>7.7</td>
<td>4.9</td>
</tr>
<tr>
<td><strong>Staff (Nurses and Medical Assistants)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consented (%)</td>
<td>11/17 (65%)</td>
<td>10/19 (53%)</td>
<td>21/25 (84%)</td>
<td>20/24 (83%)</td>
<td>10/11 (91%)</td>
<td>9/11 (82%)</td>
</tr>
<tr>
<td>Mean hours observed</td>
<td>3.5</td>
<td>3.8</td>
<td>3.7</td>
<td>3.7</td>
<td>3.8</td>
<td>3.7</td>
</tr>
<tr>
<td>Mean number of minutes unable to observe</td>
<td>1.0</td>
<td>2.3</td>
<td>1.9</td>
<td>1.2</td>
<td>0.5</td>
<td>1.4</td>
</tr>
</tbody>
</table>

**Total:** 146 observations /179 possible times (82%); 45% (65 obs.) prescribers, 29% (43) nurses, 26% (38 medical assistants; 47% (69 obs) in phase 1, 53% (77) in phase 2; **Paired:** 96 observations; 52% (50 obs.) prescribers, 21% (20) nurses, 27% (26) medical assistants
## Results – seconds to prescribe (2)

### Table 2.1: Time spent hand-writing and e-Prescribing for Prescribers

<table>
<thead>
<tr>
<th></th>
<th>Mean seconds per prescription event (number of prescriptions)</th>
<th>Mean seconds per prescription event Adjusted difference; unpaired analysis (99.5% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Handwritten (Phases 1 and 2 combined)</td>
<td>E-prescribed on desktops in examination rooms (Phase 2)</td>
</tr>
<tr>
<td>All Sites – all prescriptions †</td>
<td>47 (132)</td>
<td>69 (312)</td>
</tr>
<tr>
<td>All sites – new prescriptions † ‡</td>
<td>47 (111)</td>
<td>75 (181)</td>
</tr>
<tr>
<td>All sites – renewed prescriptions † ‡</td>
<td>46 (21)</td>
<td>63 (131)</td>
</tr>
<tr>
<td>E-prescribed (Phase 1)</td>
<td></td>
<td>E-prescribed on desktops in examination rooms (Phase 2)</td>
</tr>
<tr>
<td>Harbour Pointe – all prescriptions ‡</td>
<td>44 (79)</td>
<td>70 (147)</td>
</tr>
<tr>
<td>Harbour Pointe – new prescriptions</td>
<td>45 (37)</td>
<td>74 (84)</td>
</tr>
<tr>
<td>Harbour Pointe – renewed prescriptions</td>
<td>42 (42)</td>
<td>63 (63)</td>
</tr>
<tr>
<td>Snohomish – all prescriptions ‡</td>
<td>73 (59)</td>
<td>73 (69)</td>
</tr>
<tr>
<td>Snohomish – new prescriptions</td>
<td>75 (43)</td>
<td>83 (38)</td>
</tr>
<tr>
<td>Snohomish – renewed prescriptions</td>
<td>66 (16)</td>
<td>61 (31)</td>
</tr>
</tbody>
</table>

CI = confidence interval  
*p<0.005; **p<0.001  
Linear mixed effects models – random effect = prescriber  
† fixed effects = clinic, new/renewed prescription, days exposed to computer hardware, days exposed to e-prescribing software  
‡ fixed effects = clinic, days exposed to computer hardware, days exposed to e-prescribing software  
⊕ fixed effects = clinic, new/renewed prescription
Results-min/hr on tasks(3)

Prescribers

Silver Lake

Harbour Pointe

Snohomish

mean of minutes_hour

P<0.001

NS when combined with writing

Phase 1

Phase 2
Results - min/hr on tasks (4)
Results—Overall Activities (5)

Overall activity Types

Prescribers
- Administrative
- Direct Patient Care
- Miscellaneous
- Indirect Patient Care-Other
- Indirect Patient Care-Read
- Indirect Patient Care-Write

Staff
- Administrative
- * Direct Patient Care
- * Miscellaneous
- * Indirect Patient Care-Other
- Indirect Patient Care-Read
- Indirect Patient Care-Write

*p<0.001

Proportion of time spent
- Phase 1
- Phase 2
Notable Findings

• E-prescribing took 22 secs/ prescription longer than handwriting
  – 18 seconds per patient
• E-prescribing in phase 2 took 22 secs/ prescription longer than in phase 1
  – Computers in exam rooms – at point of care
• Prescribers spend most time talking to patient; little time prescribing
• Staff spend more time computing & talking
• Time spent in direct patient care
  – unchanged for prescribers
  – Increased for staff (corresponding decrease in miscellaneous tasks)
Strengths and Limitations

- Time-motion methods – gold standard
- Includes staff
- Reflects pre-, post-implementation of 3 configurations

- Hawthorne effect¹
  - limited to specific time periods during the day
  - limited to primary care clinics
  - limited ability to accurately capture simultaneously occurring tasks
  - did not capture total amount of time worked per day; unable to determine impact on workload

Study #3: Focus Group Study

• **Aim 3.1**: Explore and describe end-users’ perceptions of and experiences with the CPOE system

  • **Hypothesis**: perceptions will be generally favorable

• **Aim 3.2**: Map results to the information technology acceptance model (ITAM)\(^1\)

---

\(^1\) Dixon. Int J Med Inform 1999; 56: 117-23
Background

• Many barriers to EHR adoption\textsuperscript{1-4}:
  – overall prescriber resistance due to perceived time-intensity and lost productivity

• EHRs can:
  – facilitate medication errors\textsuperscript{5}
  – cause alert fatigue\textsuperscript{6}
  – cause a revolt against implementation\textsuperscript{7}

• Successful implementation\textsuperscript{8}
  – Leadership, motivation, attention to workflow, staged implementation, technical details, training, continuous improvement

• POET Group\textsuperscript{8} – qualitative research; inpatient focused; one HMO

\textsuperscript{1}Grossman. Health Aff 2007; \textsuperscript{2}Doolan. Health Aff.2002; \textsuperscript{3}Poon. Health Aff 2004; \textsuperscript{4}Halamka. JAMIA 2006; \textsuperscript{5}Koppel. JAMA 2005; \textsuperscript{6}Weingart. Arch Intern Med 2003; \textsuperscript{7}Shane. AJ HP 2003; \textsuperscript{8}Ash. JAMIA 2003
Information Technology Adoption Model

Figure 3.1: Enhanced Information Technology Adoption Model
Methods (1)

• Study Design: Qualitative, focus groups; cross sectional
• Enrich / complement Studies #1 and #2
• Sampling frame: 3 primary care clinics
  – universal
  – voluntary
• Inclusion criteria: all end-users involved with the prescribing process
  – prescribers = MDs, DOs, ARNPs, PAs
  – staff = RNs, medical assistants
• 3-8 participants/group; 30 minutes/ group
• 2 groups/clinic (prescribers & staff)
• Academic investigator to facilitate focus groups
**Methods (2)**

- On-site consent
- Semi-structured elicitation techniques developed from review of literature (interview guide)\(^1\)
- Content recorded on laptop, capturing comments “*verbatim*”

3 topical areas
- expectations and impact
- Fears
- Barriers
- (individual level variables)

- Approved by the UW Human Subjects Committee

\(^1\)Miles & Huberman. *Qual Data Analysis*. Sage; 1994
## Focus Group Details

<table>
<thead>
<tr>
<th></th>
<th>Silver Lake (Spring 2005)</th>
<th>Harbour Pointe (Summer 2005)</th>
<th>Snohomish (Summer 2006)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participants</td>
<td>Prescribers (7)</td>
<td>Prescribers (6+)</td>
<td>Prescribers (3)</td>
</tr>
<tr>
<td></td>
<td>Staff (8)</td>
<td>Staff (9)</td>
<td>Staff (4)</td>
</tr>
<tr>
<td>Software/Hardware</td>
<td>Paper; EHR-deskops</td>
<td>CPOE (11 mos); EHR-deskops</td>
<td>CPOE (22 mos); EHR-laptops</td>
</tr>
<tr>
<td>Hardware configuration</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2 extra focus groups: “float pool staff” and Silver Lake staff “transition timeframe” (6 mos. post-CPOE implementation)
Data Management & Analyses (1)

- Unit of analysis = focus group
  - site, type of health care professional, and date
- 2 coders & epistemology
  - 1) deductive\(^1\)
    - (starting with a set of analytic categories)
  - phenomenological approach\(^1\)
    - (open to new ideas, not pre-judging, just describing)
  - 2) grounded theory
- Analysis\(^1-3\)
  - hermeneutic style\(^2\) - Atlas.ti\(^{TM}\)
  - coding – open; microanalytic; constant comparison; theoretical saturation; ‘check coding’ comparison
  - axial coding – process of relating major categories to each other
  - Creation and comparison of themes across focus groups & end-user profession

\(^1\)Strauss & Corbin, 1998; \(^2\)Bradley.HSR 2007;42:1758-72; \(^3\)Miles & Huberman, 1994
Data Management & Analyses (2)

- 8 focus groups; 70 participants; 24% prescribers
- 26 pages of transcripts
- 142 codes;
- 26 code families
- Dimensionality
  - Prescribers & staff
  - Pre- vs. Post- CPOE

<table>
<thead>
<tr>
<th>Pre-CPOE</th>
<th>Post-CPOE</th>
</tr>
</thead>
<tbody>
<tr>
<td>SL Spring</td>
<td>HP, Sno, Float, SL Fall</td>
</tr>
<tr>
<td></td>
<td>(transition)</td>
</tr>
<tr>
<td>Expectations vs. Concerns/</td>
<td>Benefits vs. Drawbacks</td>
</tr>
<tr>
<td>fears</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Improvements needed (wish list)</td>
</tr>
<tr>
<td></td>
<td>Promoters vs. Barriers (float pool)</td>
</tr>
<tr>
<td>Results - Themes</td>
<td></td>
</tr>
<tr>
<td>------------------</td>
<td></td>
</tr>
<tr>
<td><strong>Clinical information</strong></td>
<td><strong>Software &amp; hardware configurations</strong></td>
</tr>
<tr>
<td>(CDS features)</td>
<td>(reliability, security, speed)</td>
</tr>
<tr>
<td><strong>Documentation &amp; safety</strong></td>
<td><strong>Implementation, transition &amp; improvement</strong></td>
</tr>
<tr>
<td>(medication safety)</td>
<td>(transition processes)</td>
</tr>
<tr>
<td><strong>Organizational issues</strong></td>
<td><strong>Time</strong></td>
</tr>
<tr>
<td>(training and support)</td>
<td>(time-saving, time-neutral)</td>
</tr>
<tr>
<td><strong>Efficiency</strong></td>
<td><strong>Overall impressions</strong></td>
</tr>
<tr>
<td>(less paper/ fewer charts)</td>
<td></td>
</tr>
<tr>
<td><strong>Patients</strong></td>
<td><strong>End-user characteristics</strong></td>
</tr>
<tr>
<td>(computers at point of care → coordination; satisfaction)</td>
<td>(age, attitudes, computer experience)</td>
</tr>
<tr>
<td><strong>Pharmacy communications</strong></td>
<td>(integration/ transparency)</td>
</tr>
</tbody>
</table>
Figure 3.2: Mapping Focus Group Results to the Enhanced TIAM
Notable Findings

- Improvements in access, accuracy, documentation, integration, transparency
- Reduction in medication errors (2ndary)
- Large initial investment of time (staff)
- Staff early adopters
- Good training/more training
- CDS alerts (prescribers); internal communications (staff)
- Workload shift to staff; but worth it
- Less paperwork; fewer charts
- Network challenges, pharmacy challenges
- Computers at point of care (care coordination)
- Remote access (care coordination)
- Time neutral (prescribers)
- Improved patient satisfaction
- Positive attitudes (or reserved, but not negative)
- Benefits realized; fears were not; favorable impressions
Strengths and Limitations

• Includes staff

• Cross-sectional data

• Primary care clinics

• Voluntary participation
  – Those with positive attitudes may have participated

• Two focus groups conducted by member of system implementation team

• Written transcripts only
Contributions to the Field

• Collection of 3 studies
• Results suggest a basic CPOE system can be successfully implemented in community-based setting, not affiliated with academic medical center
  – improved medication safety
  – time neutrality
  – favorable impact
• Lessons learned to enable successful adoption¹

¹Devine AHRQ Publications 2008
Contributions to the Field

• Results generalizable in many ways due to universal issues involved in CPOE adoption\textsuperscript{1-4}
  – optimize background information databases
  – identify core functions; user-friendly screen functionality
  – proactive planning of revised workflow to ensure time-efficiency and productivity
  – address network reliability, security, integration
  – organizational, cultural and environmental issues

• Limited generalizability, but important findings
  – homegrown system
  – staged implementation
  – iterative improvements

\textsuperscript{1}Bell, Health Affairs May 25, 2004; \textsuperscript{2}Bell, JAMIA 2004; \textsuperscript{3}Poon, Health Affairs 2004;
\textsuperscript{4}Devine AHRQ Publications 2008
Collaborators

• UW
  • Dave Blough, PhD
  • Will Hollingworth, PhD
  • Diane Martin, PhD
  • Tom Payne, MD
  • Sean Sullivan, PhD
  • Peter Tarczy-Hornoch, MD
  • Ryan Hansen, PharmD; Tom Hazlet PharmD, DrPH, Emily Williams, MS, Bryan Comstock, MS

• The Everett Clinic
  • Al Fisk, MD, MMM
  • Nathan Lawless, ChE, RPh
  • Jennifer Wilson-Norton, RPh, MBA
Thank you!
Supporting Slides
<table>
<thead>
<tr>
<th>NCCMERP Category</th>
<th>Description of NCCMERP Category</th>
<th>Bates' ADE Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Error</td>
<td>Circumstances or events that have the capacity to cause error</td>
<td>Rule violations</td>
</tr>
<tr>
<td>A</td>
<td>An error occurred, but the medication did not reach the patient</td>
<td>Intercepted potential ADE</td>
</tr>
<tr>
<td>B</td>
<td>An error occurred that reached the patient but did not cause patient harm</td>
<td>Non-Intercepted potential ADE</td>
</tr>
<tr>
<td>C</td>
<td>An error occurred that resulted in the need for increased patient monitoring but no patient harm</td>
<td>Non-Intercepted potential ADE</td>
</tr>
<tr>
<td>D</td>
<td>An error occurred that resulted in the need for treatment or intervention and caused temporary patient harm</td>
<td>Preventable ADE</td>
</tr>
<tr>
<td>E</td>
<td>An error occurred that resulted in initial or prolonged hospitalization and caused temporary patient harm</td>
<td>Preventable ADE</td>
</tr>
<tr>
<td>F</td>
<td>An error occurred that resulted in permanent patient harm</td>
<td>Preventable ADE</td>
</tr>
<tr>
<td>G</td>
<td>An error occurred that resulted in a near-death event (e.g., anaphylaxis, cardiac arrest)</td>
<td>Preventable ADE</td>
</tr>
<tr>
<td>H</td>
<td>An error occurred that resulted in patient death</td>
<td>Preventable ADE</td>
</tr>
</tbody>
</table>

Two Weighting Schemas

1) proportion of prescriptions retrieved and evaluated from each of 3 on-site pharmacies reflects proportion filled at each of 3 pharmacies, during 12 month timeframe

2) analysis weighted to reflect clinic-wide prescribing practices
   • Adjusted for prescriber specialty & therapeutic drug class
   • Stratified by onsite pharmacy from which prescription retrieved
   • R x C tables – proportion of scripts represented by each pair of provider specialty and drug class, within each pharmacy
   • R x C table – same elements from 12 months of claims data from all clinics, all pharmacies
   • Ratio – numerator = claims; denominator = study data
   • Each ratio applied to each prescription in dataset
Med Error Study-Analyses (1)

- **Aim 1**: Estimate unadjusted differences in error characteristics:
  \[
  \frac{p_1 - p_2}{\sqrt{p_0(1-p_0)(1/n_1 + 1/n_2)}}; \quad \text{where} \quad p_0 = \frac{X_1 + X_2}{n_1 + n_2}
  \]

- **Aim 1**: Estimate error distribution and severity – binary outcomes
  - Hierarchical data – prescription, prescriber, provider/clinic type, geographic site
  - Generalized estimating equations (GEE) with alternating logistic regression (ALR)
  - GEE – an extension of generalized linear models: \( g(\mu_{ij}) = X'_{ij}\beta \); GEE adds the covariance component; used for first order models (mean and (co)variance)
  - ALR:
    - **Step 1**: logistic regression using 1st order GEE to estimate regression coefficients (\( \beta \)); binomial distribution; logit link
    - **Step 2**: logistic regression of each response on others from the same cluster, using an offset to update the odds ratio parameters; estimate pairwise odds ratios for within cluster associations (\( \alpha \)), conditional on \( \beta \)

\(^1\text{Carey. Biometrika 1993;80:517-26}\)
Med Error Study–Analyses (2)

- Equation to estimate the dependence of the outcome on the covariates (β’s):

  \[
  \text{Logit } \Pr(Y_{hijk}=1|X_{hijk}) = \beta_0 + \beta_1(\text{e-prescribing}) + \beta_2(\text{cov}_{hijk})
  \]

- Equation to estimate the pairwise odds ratios for the within cluster associations (α’s) while simultaneously taking into account the β’s:

  \[
  \text{log odds ratio } (Y_{hijk} = 1) = \alpha_0 + \alpha_1 Z_{hijkl\ell'k'} + \alpha_2 Z_{hijkl\ell'k'}
  \]

- Pairwise odds ratios will describe the odds in favor of an error occurring for a prescription within that level, when compared to a second prescription from within that same level of association.

- The results of the algorithm should return estimates that specify the odds ratios of an error occurring, given each covariate; as well as odds ratios for within prescriber, within provider/clinic type, and within geographic site, each adjusted for the covariates.
Sample Size Calculation: Study #1

- Pilot study error rate = 28%
- Estimated error rate for this study = 25%
- 5% reduction$^1$ - to 24%
- 2 adult; 2 pediatric clinics
- 2-sample, 2-sided, $\chi^2$ test; $\alpha = 0.05$; 80% power
- 1,222 prescriptions/clinic
- 10,000 prescriptions

$^1$Bates, JGIM 1995;10:199-205
Power Calculation Med Errors (1):

- Average # scripts/ prescriber = 120
- Use an ICC of 0.02
- Variance inflation factor (VIF) = $1 + [(m -1) \times ICC]$
  - VIF = $1 + (120-1)(0.02) = 3.38$
  - $10,169/3.38 = 3,009$ scripts
- 49% pre-; 51% post =
  - 1,474 pre and 1,535 post
Power Calculation Med Errors (2):

- . sampsi 0.25 0.20, n1(1474) n2(1535)
- Estimated power for two-sample comparison of proportions
- Test Ho: p1 = p2, where p1 is the proportion in population 1
  and p2 is the proportion in population 2
- Assumptions:
  - alpha = 0.0500 (two-sided)
  - p1 = 0.2500
  - p2 = 0.2000
  - sample size n1 = 1474
  - n2 = 1535
  - n2/n1 = 1.04
- Estimated power:
  - power = 0.9002
Data Collection Tool

All timing data collected with Timer Pro™

http://performance-measurement.com/
**Aim 2c: Linear Mixed Model**

\[ E(Y_{ij} | X_{ij}) = \beta_0 + \beta_1(\text{stage of e-prescribing}) + \beta_2(\text{prescriber}) + \beta_3(\text{covariate}_{ij}) + b_{0i} + \varepsilon_{ij} \]

where

- \( Y \) = adjusted mean difference in the number of seconds spent pre prescription/related event, for prescribers
- \( \beta_1 \) = stage of e-prescribing
- \( \beta_2 \) = prescriber (random effect)
- \( \beta_3 \) = new or refilled prescription (fixed effect)
- \( b_{0i} \) = random intercept between prescriber
- \( \varepsilon_{ij} \) = error term within clusters

i=index for cluster/subject (prescriber)
j=index for measurement within cluster (prescribing event)
Power Calculation-Time Motion (1)

• Aim 2c – Silver Lake site
  – 10 prescribers
  – Write 10 prescriptions / 4 hour time block
    • 50 ± 5 secs to hand-write
    • 60 ± 5 secs to e-prescribe
  – Assume
    • ICC = 0.01
  – Variance inflation factor (VIF) = 1 + [(m -1) * ICC]
    – VIF = 1 + [(10-1)0.01] = 1.09
  – 2-sided test; α = 0.05

• 95% power to detect 20% difference in time to write a prescription
Power Calculation-Time Motion (2) Updated (1)

- Number of prescribers = 25 pairs and 15 singles
- 35 prescribers
  - Write 8 prescriptions / 4 hour time block
    • 50 ± 5 secs to hand-write
    • 60 ± 5 secs to e-prescribe
  - Assume
    • ICC = 0.01
  - Variance inflation factor (VIF) = 1 + [(m -1) * ICC]
    - VIF = 1 + [(8-1)0.01] = 1.07
  - 132 handwritten + 312 e-prescribed events = 444 events
    - 444/1.07 = 415
  - 125 (30%) handwritten; 290 (70%) e-prescribed
. sampsi 50 60, n1(125) n2(290) sd(5)

Estimated power for two-sample comparison of means

- Test Ho: m1 = m2, where m1 is the mean in population 1 and m2 is the mean in population 2
- Assumptions:
  - alpha = 0.0500 (two-sided)
  - m1 = 50
  - m2 = 60
  - sd1 = 5
  - sd2 = 5
  - sample size n1 = 125
  - n2 = 290
  - n2/n1 = 2.32

- Estimated power:
  - power = 1.0000