### Purpose
- **User satisfaction**
- **Positive user satisfaction**
- **Barriers**
- **Strengths**

### Design
- **Retrospective observational**
- **Prospective observational**

### Sample/Setting
- **Academic hospital (631 beds)**
- **Teaching hospital**
- **Pediatric hospital in the Midwest**
- **General Internal Medicine, Brigham and Women’s Hospital, Boston, MA, USA**
- **Center for Excellence in Nursing Practice, Brigham and Women’s Hospital, Boston, MA, USA**

### Outcome measure
- **Smart pump event logs**
- **Smart pump event classification index**
- **NCC MERP ADE risk as per collection form**
- **Smart pumps data collection**
- **Electronic data**

### Compliance rate
- **93% (drug library)**
- **71%**
- **36 of 37 rate deviation errors were not preventable by smart pump**
- **67% of observed drugs had errors in their administrations**
- **Smart pumps are unlikely to diminish errors unless they are fully integrated with other systems**

### Type of alerts
- **One 150-fold rate potential error prevented**
- **Most alert occurred between 3:00PM and 7:00PM. Overdose: majority or override: propofol bolus**
- **Errors were unlikely to be prevented by smart pumps**
- **Smart pump do not detect secondary flow**
- **Smart pump handling errors can be critical**

### Medication errors/prevented ADEs
- **88% override**
- **506 alerts (73% overdose, 22% Undertakes, 88% override, 12% reprogram)**
- **Errors generated among 413078 programs. Undertakes (12%) Overdose (58%) Overriders (84%)**
- **Estimated cost avoidance of $2,000,000 per year for CHS**
- **Errors prevented by smart pumps**

### Other findings
- **Need for wireless connection for real time CQI data and integration with CPOE**
- **Prevention of potentially serious errors. Training helps successful implementation. Positive use satisfaction**
- **Collected data in the pump for safety improvement**
- **Some errors could have been prevented with smart pump technology. Using hard limits. Including smart pumps in an integrated safety system could reduce errors**
- **Smart pumps have only access to dose ranges, while integrated system could prevent more errors. Need logics for rate increasing limits**
- **Different providers ordering in CPOE and programming the smart pump is a source of discrepancies. Process of prescribing matters**

### Barriers
- **Alert fatigue**
- **Log data is useful for patient safety. Error prevention at the point of care**
- **Needed to distinguish alerts for bolus doses**
- **No baseline data to compare**
- **Prevented errors were significant. Positive user satisfaction**

### Estimated cost avoidance
- **$29,120,000 per year for CHS**

### Medication errors/secondary flow
- **12% reprogram**
- **88% override**
- **Underdoes (12%)**
- **Overrides (84%)**

### Potential error
- **181 medications observed**
- **426 medications observed**
- **12 patients**
- **67% of observed drugs had errors in their administrations**
- **Smart pumps are unlikely to diminish errors unless they are fully integrated with other systems**

### Prevention of harms
- **High acceptance. Prevention of harms**
- **No baseline data to compare**
- **Prevented errors were significant. Positive user satisfaction**

### Strengths
- **User satisfaction**
- **Positive user satisfaction**
- **Barriers**
- **Strengths**

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**Benefits and Risks of Using Smart Pumps to Reduce Medication Error Rates: a Systematic Review**

Electronic Supplementary Material 1
**Benefits and Risks of Using Smart Pumps to Reduce Medication Error Rates: a Systematic Review**

**Electronic Supplementary Material 1**

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Nuckols, 2008, USA [26]</td>
<td>To determine how frequently preventable IV-ADEs in ICUs match the safety features of smart pumps To suggest potential improvements in smart pump design</td>
<td>Before-after comparison Retrospective review</td>
<td>2 hospitals (1 academic and 1 non-academic) 4,604 patients with 20,559 bed-days in ICUs</td>
<td>Medical-record review Reports of preventable IV-ADEs</td>
<td>Of 100 preventable IV-ADEs (4.86 per 1,000 patient-days) identified, 4 involved errors matching smart-pump features. 2 occurred before and 2 after smart-pump implementation</td>
<td>Unlikely to reduce preventable IV-ADEs in ICUs because they address only 4% of them</td>
<td>Need to expand library applications, integrating pumps with vital sign and lab data, integrating pumps with CPOE and automating medication titration</td>
<td>Need to address boluses</td>
<td>Potential severe errors resulting from programming errors were intercepted</td>
<td></td>
</tr>
<tr>
<td>Previtt, 2013, USA [25]</td>
<td>To evaluate the incidence and clinical characteristics and ADE-S among adults receiving opiates in PCA and smart pump</td>
<td>Before-after comparison Retrospective review</td>
<td>A tertiary and quaternary care hospital Adults receiving opiates in PCA 28 months before (21,107 PCA days), 23 months after (18,117 PCA days)</td>
<td>Voluntary reporting system (VRS) events Adverse drug events via surveillance (ADE-S)</td>
<td>ADE-S PCA events per 1000 PCA days decreased 22%, from 5.3 (pre) to 4.2 (post) (P &lt; 0.09) Voluntary report system events decreased 72%, from 2.4/1000 PCA days (pre) to 0.66/1000 PCA days (post) (P &lt; 0.001)</td>
<td>The rate of alerts is higher during afternoon, (when admissions, transfer and shift change) Attempts to reprogram the same incorrect information Errors not intercepted; wrong drug, allergy, omission, discontinued Programming errors are frequently duplicated</td>
<td>ADE-S: still need for close monitoring of the patient</td>
<td>High probability to reduce ADE-S</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fanikos, 2007, USA [23]</td>
<td>To detect the impact of smart pumps on error rates of administration of anticoagulants</td>
<td>Before-after comparison</td>
<td>Teaching hospital Adults receiving heparin in 3674 patients 16 months observation before (355 patients), 16 months after (246 patient)</td>
<td>Smart pump event logs Self reported anticoagulation errors</td>
<td>After 863 alerts (501 hard limits, 362 soft limits) 59.8% underdose 31.3% overdose 8.9% duplicate drug therapy 46.5% cancel 43.1% reprogram 10.4% override The user attempted to reprogram the same incorrect information in 27.2% of the alerts</td>
<td>After: 48 self-reported errors (no difference in number or frequency as compared to “before” 49) After: 4 infusion rate errors Before: 15 infusion rate errors</td>
<td>The user attempted to reprogram the same incorrect information Errors not intercepted; wrong drug, allergy, omission, discontinued Programming errors are frequently duplicated</td>
<td>Prevent keypad errors due to transcription Smart infusion technology helps intercept keypad entry errors</td>
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<td>Kastrup, 2012, Germany [30]</td>
<td>To analyze the effect on potential harmful medication errors pumps</td>
<td>Retrospective pilot study</td>
<td>Academic hospital ICUs 20 months 7884 patients 133601 infusions</td>
<td>Smart pump event logs</td>
<td>92.8% syringe pumps with drug library, 1.5% manual-dosing mode, 5.7% without any calculation features</td>
<td>1063 dose-related alerts 9 no concentration recorded 10 overdose above hard limit 698 overdose soft limit 346 underdoses soft limit 66 reprogramming 4 cancel</td>
<td>Need for integration with clinical systems Not activated bolus function</td>
<td>Need to expand library applications, integrating pumps with vital sign and lab data, integrating pumps with CPOE and automating medication titration</td>
<td>Intercept potential serious medication errors Pump recording is an important benefit of smart pumps</td>
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<tr>
<td>Maanrique Rodrigez S, 2013, Spain [13]</td>
<td>To describe the impact of smart pumps on errors in programming IV drug administration</td>
<td>Prospective observational intervention</td>
<td>Children academic hospital, PICU 17 months</td>
<td>Smart pump event logs Potential severity of intercepted</td>
<td>78% (drug library): syringe-pump: 86%, large volume pump: 36%</td>
<td>97% of alerts (dose or rate above the hard limits) 70% of soft limit override</td>
<td>92 intercepted errors 49% of the errors could have been of moderate, serious, or catastrophic severity consequence</td>
<td>Override of soft alerts, usefulness of soft limits is questionable Low compliance for large volume pump due to display issue Absence of wireless connection Need for improved interfaces</td>
<td>Potential severe errors resulting from programming errors were intercepted</td>
<td>No other significant barriers identified</td>
</tr>
</tbody>
</table>

**Electronic Supplementary Material 2**

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<tr>
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### Other findings

- **Barriers**
  - Override of soft alerts, usefulness of soft limits is questionable
  - Low compliance for large volume pump due to display issue
  - Absence of wireless connection
  - Need for improved interfaces

- **Strengths**
  - Intercept potential serious medication errors
  - Pump recording is an important benefit of smart pumps

### Purpose

- **To describe the impact of smart pumps on errors in programming IV drug administration**
  - Prospective observational intervention
  - Children academic hospital, PICU 17 months
  - Smart pump event logs Potential severity of intercepted
  - 78% (drug library): syringe-pump: 86%, large volume pump: 36%
  - 97% of alerts (dose or rate above the hard limits) 70% of soft limit override
  - 92 intercepted errors 49% of the errors could have been of moderate, serious, or catastrophic severity consequence
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  - 1063 dose-related alerts 9 no concentration recorded 10 overdose above hard limit 698 overdose soft limit 346 underdoses soft limit 66 reprogramming 4 cancel
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  - Before-after comparison
  - Teaching hospital 14012 administered doses of heparin in 3674 patients 16 months observation before (355 patients), 16 months after (246 patient)
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  - ADE-S: PCA events per 1000 PCA days decreased 22%, from 5.3 (pre) to 4.2 (post) (P < 0.09) Voluntary report system events decreased 72%, from 2.4/1000 PCA days (pre) to 0.66/1000 PCA days (post) (P < 0.001)

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  - Before-after comparison Retrospective
  - 2 hospitals (1 academic and 1 non-academic) 4,604 patients with 20,559 bed-days in ICUs
  - Medical-record review Reports of preventable IV-ADEs
  - Of 100 preventable IV-ADEs (4.86 per 1,000 patient-days) identified, 4 involved errors matching smart-pump features. 2 occurred before and 2 after smart-pump implementation

### Other findings

- **Barriers**
  - Override of soft alerts, usefulness of soft limits is questionable
  - Low compliance for large volume pump due to display issue
  - Absence of wireless connection
  - Need for improved interfaces

- **Strengths**
  - Intercept potential serious medication errors
  - Pump recording is an important benefit of smart pumps
## Benefits and Risks of Using Smart Pumps to Reduce Medication Error Rates: a Systematic Review

### Electronic Supplementary Material 1

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<tr>
<td>Tran M, 2012, USA [28]</td>
<td>To evaluate intercepted errors with smart PCA pumps and to assess nursing perceptions</td>
<td>Before after comparison</td>
<td>6 months for pump logs 1 year before; one year after for ADE reporting (in 2005 &amp; 2007)</td>
<td>Smart pump event logs: Voluntarily reported PCA therapy related errors Error severity rating (NCC MERP index) ADE risks Nursing perceptions</td>
<td>Wrong concentration was eliminated after implementation Before-after: no significant reduction of wrong dose errors 92% override of soft alerts (n=526)</td>
<td>Of 159 errors, 96(60%) of the prevented errors were potentially significant More severe errors was increased (pre 16% to post 46%) The most frequent errors: pump-programming error (80% to 30%), omission (23 to 26%), prescribing errors (15 to 16%)</td>
<td>One error of wrong selecting information</td>
<td>Need for integration with clinical systems Need for pump log data analysis to improve safety Possibility of alert fatigue (override soft limits)</td>
<td>Greater benefits of hard limits Positive user perception</td>
<td></td>
</tr>
<tr>
<td>Larsen, 2005, USA [24]</td>
<td>To determine if combining standard drug concentrations with “smart pump” technology reduces reported medication-error associations</td>
<td>Before-after comparison</td>
<td>Academic tertiary pediatric hospital (242 beds) 12 months before, 12 months after</td>
<td>Reported medication errors captured by the hospital’s incident-reporting system</td>
<td>87% in the NICU &gt;99% in other areas</td>
<td>The number of reported errors dropped by 73%. Error rate decreased from 3.1 to 0.8 per 1000 doses. The number of 10-fold errors in dosage increased from 0.41 to 0.08 per 1000 doses.</td>
<td>Reduce likelihood of confusing units and eliminate unit conversions</td>
<td>Decrease in reported errors Shift the calculation burden to computer Provide feed-back, facilitate double check</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paul, 2010, Canada [27]</td>
<td>To compare the incidence of PCA errors in the preintervention cohort with those of the post intervention cohort</td>
<td>Before-after comparison</td>
<td>3 tertiary care hospitals Before: 4 years After: 3 years 25198 patients with PCA</td>
<td>PCA pump-programming errors: Critical incident reports attributable to PCA ADE risk as per NCC MERP index</td>
<td>Wrong drug concentrations (48%) Wrong dose (5%) Wrong dose and wrong concentration (10%) Wrong lockout (5%) Continuous infusion added when it was not ordered (5%) Continuous infusion discontinued without order (10%) 4-h limit not programmed (10%) Wrong 4-h limit programmed (5%)</td>
<td>62 errors (0.25%): 21 (0.08%) programming pump errors All errors occurred before implementation of pumps Significant decrease of pump-programming errors after implementation Most PCA errors resulted in no harm, but negative impact on patients in 34% of the time</td>
<td>Previous pump: need to scroll several screens to see parameters Further improvements in safety are possible with the use of eMAR/CPOE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pang, 2011, Australia [1]</td>
<td>To measure and characterize intravenous medication administration errors</td>
<td>Before after comparison</td>
<td>An acute care teaching hospital (380 beds) 41 days before (432 infusions) 27 days after (266 infusions)</td>
<td>IV administration details (drug prescribed, dose, frequency, rate, volume) Evaluated the clinical significance of the identified errors</td>
<td>Before: 18% of infusions had one or more errors After: 9.4% infusions had one or more errors (p=0.003) 79% reduction of errors with drug library, while no significant difference without it</td>
<td>Before: 1 ‘extreme’ and 30 errors with ‘high’ clinical significance After: no errors of ‘extreme’ clinical significance and only 1 error of ‘high’ clinical significance (P=0.03)</td>
<td>Smart pump will not prevent all types of errors and may introduce new types of errors Need for education to improve compliance rate</td>
<td>Significant error reduction with drug library use</td>
<td></td>
<td></td>
</tr>
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---

**Authors:** Tran M, 2012, USA
Larsen, 2005, USA
Paul, 2010, Canada
Pang, 2011, Australia

**Purpose:**
- To evaluate intercepted errors with smart PCA pumps and to assess nursing perceptions
- To determine if combining standard drug concentrations with “smart pump” technology reduces reported medication-error associations
- To compare the incidence of PCA errors in the preintervention cohort with those of the post intervention cohort
- To measure and characterize intravenous medication administration errors

**Design:**
- Observational
- Longitudinal
- Before after

**Sample/Setting:**
- Academic tertiary pediatric hospital (242 beds)
- 3 tertiary care hospitals
- An acute care teaching hospital (380 beds)

**Outcome measure:**
- Reported medication errors captured by the hospital’s incident-reporting system
- PCA pump-programming errors
- IV administration details

**Compliance rate:**
- 87% in the NICU >99% in other areas

**Type of alerts:**
- Wrong drug concentrations
- Wrong dose
- Wrong dose and wrong concentration
- Wrong lockout
- Continuous infusion added when it was not ordered
- Continuous infusion discontinued without order
- 4-h limit not programmed
- Wrong 4-h limit programmed

**Medication errors/ prevented ADEs:**
- Of 159 errors, 96(60%) of the prevented errors were potentially significant
- More severe errors was increased (pre 16% to post 46%)

**Other findings:**
- The number of reported errors dropped by 73%. Error rate decreased from 3.1 to 0.8 per 1000 doses.

**Barriers:**
- Previous pump: need to scroll several screens to see parameters

**Strengths:**
- Greater benefits of hard limits
- Positive user perception

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**Note:**
- NCC MERP: National Coordinating Council for Medication Error Reporting and Prevention
- ADE: Adverse Drug Event
- NICU: Neonatal Intensive Care Unit
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<tbody>
<tr>
<td>Trbovich, 2010, Canada [11]</td>
<td>To assess the impact of infusion pump technologies (traditional pump vs. smart pump vs. smart pump with barcode) on nurses’ ability to safely administer intravenous medications</td>
<td>Experimental study with a repeated measures design</td>
<td>High fidelity simulated inpatient unit. 24 nurses</td>
<td>Number of corrected errors, Pump programming accuracy</td>
<td>The nurses corrected 60% of “wrong drug” errors. The nurses corrected “wrong patient” errors more often when using the barcode pump (88%) than when using the smart pump (58%) (p &lt; 0.05). The number of nurses who corrected “wrong dose hard limit” errors was higher when using the smart pump (75%) and the barcode pump (79%) than when using the traditional pump (38%) (p = 0.003).</td>
<td>More errors when mathematical conversions were required</td>
<td>No significant effect of soft limits</td>
<td>Need for integration with clinical systems</td>
<td>No pump helped detect wrong drug</td>
<td>More effective when combined with barcode. Hard limits prevent errors</td>
</tr>
<tr>
<td>Gerhart, 2013, USA [20]</td>
<td>To describe an impact on patient safety of an integrated system</td>
<td>Descriptive Retrospective</td>
<td>1 hospital 6 months</td>
<td>Smart pump event logs, Observations and reports or errors</td>
<td>97%</td>
<td>782 significant near-miss medication errors (upper hard limits) 39.5% of reprogram of soft limits 77.5% of reprogram of hard limits</td>
<td>27% reduction in nursing time. Potential cost avoidance</td>
<td></td>
<td>Improved accuracy of programmed medication. Integration prevents major type of errors, including wrong drug and wrong patient. Pharmacy based monitoring. Real-time data available for providers</td>
<td></td>
</tr>
<tr>
<td>Skledar, 2013, USA [22]</td>
<td>To describe an implementation of a smart pump CQI program</td>
<td>Descriptive Retrospective</td>
<td>6000 smart pumps in its 14 inpatient units in a large health system 18 months</td>
<td>Smart pump event logs, CQI software logs, Errors and ADEs reported</td>
<td>78%</td>
<td>34% concerned the programming of continuous infusion. 41% concerned intermittent infusion, of which 70% were programming of duration times outside the limits. 11% concerned fluid infusion. Reprogram or cancel continuous infusions an average of 400 times per month</td>
<td>43% decrease pump-related ADEs reporting compared with before implementation</td>
<td>Four system wide updates were performed reducing “nuisance alerts” by about 10% per update cycle</td>
<td>Poor compliance. Alert fatigue</td>
<td>Ongoing refinements of the drug library. Standardization of concentrations. Enhancement of safety</td>
</tr>
<tr>
<td>Rothschild, 2005, USA [8]</td>
<td>To assess the impact of smart pumps (soft limits) on incidence and nature of medication errors and ADEs</td>
<td>Prospective randomized control trial</td>
<td>Teaching hospital 2 cardiac surgical, 2 ICU’s and 2 step-down units (720 bed) 16 weeks for control &amp; intervention. 744 admissions Control: 4276 patient-pump-day; 5364 IV medication ordered Intervention: 3869 patient-pump-day; 5295 IV medications ordered</td>
<td>Smart pump event logs, Chart reviews, Solicited staff report, Hospital incident reports, Computerized ADE surveillance monitor, ADE risk as per NCC MERP index, Comparison with without decision support</td>
<td>The users bypassed the drug libraries in 25% of cases</td>
<td>Control: 28 ADEs (14 preventable); 73 non interrupted potential ADE; 2.03 per 100 patient-pump-day serious medication rate. Intervention: 22 ADEs, of which 11 preventable ADEs; 82 potential non interrupted ADEs; 2.41 per 100 patient-pump-day serious medication rate. After correction for overriding of alerts and bypassing of the library: significant decrease of preventable ADEs in intervention</td>
<td>No statistically difference between control and intervention group regarding ADEs and medication errors incidences.</td>
<td>Most preventable ADEs were serious life-threatening.</td>
<td>Low compliance. Need for wireless and integration. Up to date maintenance of the library. Human performance aspects must be taken into account to successfully prevent medication errors</td>
<td>CQI data opportunities to provide feedback to care teams. Highlight of problems underrecognized before implementation of smart pumps</td>
</tr>
</tbody>
</table>

**Abbreviations:** ADE adverse drug event, PTTh partial thromboplastic time, CQI continuous quality-improvement, PCA patient controlled analgesia, IV intravenous, ICU intensive care unit, PCrU pediatric intensive care unit, CPOE computerized prescription order
References


