12. Infusion Pumps

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Introduction

In this chapter, we discuss two system-level patient safety practices that aim to reduce medication errors associated with infusion pumps, including smart pumps. One practice focuses on implementing structured process changes and redesigning workflows in order to improve efficiencies with pump use. The other focuses on investing in initial and ongoing staff training on the correct use, maintenance, and monitoring of infusion pumps.

Use of infusion pumps, and increasingly smart pumps, has become standard practice in hospitals to administer critical fluids to patients. However, there is still limited research on best practices for reducing errors and improving infusion pump use through workflow and process changes as well as education and training.

Background

Infusion pumps, common medical devices, are used to administer fluids such as nutrients or medications to patients. In comparison to manual administration of fluids, infusion pumps provide the advantage of controlled administration—the ability to deliver fluids in small volumes or at precisely programmed rates or intervals. Many newer infusion pumps are equipped with predetermined clinical guidelines, dose error reduction systems (DERSs), and drug libraries that provide a comprehensive list of medicines and fluids with dose, volume, and flow rate details. These “smart pumps” are designed to address the programming errors that traditional pumps are susceptible to by notifying a user when there is a risk of an adverse drug interaction or when the pump’s parameters are set outside of specified safety limits for the medication being administered. Alerts generated by smart pumps include clinical advisories, soft stops, and hard stops. Clinical advisories provide information about medications within the administering facility’s drug library, including prompts for correct administration, which are programmed into the pump by the facility or larger organization. Soft stops notify users that a selected dose is outside of the anticipated range for a specific medication. These alerts can be overridden without changing the pump’s settings. Hard stops alert users that a dose is out of the institution’s determined range and prohibit the infusion from being administered unless the pump is reprogrammed.[1]

As infusion pump technology continues to evolve, use of smart pumps in hospitals has increased. A report by the American Society of Health-System Pharmacists found that in 2013, 72.9 percent of all U.S. hospitals were using smart infusion pumps, compared with just 44 percent in 2007.[2] Along with this increase, many national organizations have identified implementing smart pumps as a key patient safety tool. The Institute for Safe Medication Practices (ISMP) strongly supports the use of smart pump safety features, and in 2006, the Institute of Medicine identified adoption of smart pumps as a strategy hospitals can use to help reduce the frequency and severity of medication errors.[3]

Despite the growing support for the use of smart pumps as a safety strategy, however, the literature shows varying results for the effect they have on reducing medication errors. User error, inadequate use of safety technology, incorrect programming, and equipment failures can still occur, significantly impacting patient safety.

Importance of Harm Area

The infusion pump, along with its failures and user errors, can have significant implications for patient safety because of its ubiquitous nature and frequent use to administer critical fluids. Infusion-associated medication errors are mistakes related to ordering, transcribing, dispensing, administering, or monitoring drugs.[4] From 2005 to 2009, the U.S. Food and Drug Administration (FDA) received approximately 56,000 reports of adverse events related to the use of infusion pumps, and manufacturers conducted 87 infusion pump recalls.[5] Fourteen of these recalls were categorized as Class I, in which there is a reasonable probability that use of the recalled device will cause serious adverse health consequences or death. Although many of the events reported to the FDA were related to deficiencies in device design and engineering, user errors also occurred. One study found that almost half of all infusion-associated medication errors were attributed to deviations in following procedures and documentation requirements.[4]

Intravenous (IV) infusions in particular pose risks to patient safety due to their complexity and the multiple steps required in their administration. Studies have found that IV infusion is associated with 54 percent of all adverse drug events, 56 percent of medication errors, and 61 percent of serious and life-threatening errors.[6] In addition, IV medications are twice as likely to be involved in errors that cause harms when compared to medications delivered via other routes.[7]

Smart infusion pumps have been implemented to avert possible medication errors; however, the risk of programming errors and equipment failures has not been eliminated. For example, one study found that despite use of smart pumps, 67 percent of the infusions evaluated involved one or more discrepancies.

Methods for Selecting Patient Safety Practices

Initial literature searches for patient safety practices (PSPs) in the infusion pump harm area were focused on systematic reviews and guidelines. Results of these searches were reviewed by harm-area task leads to identify PSPs, iterate on searches as needed, and refine lists of potential PSPs on which to focus this chapter of the report. Then the project Technical Expert Panel and Advisory Group were engaged via a survey to prioritize PSPs for inclusion in the report. These survey results, along with refined recommendations for PSP inclusion, were submitted to the Agency for Healthcare Research and Quality (AHRQ) for review. After several rounds of review with AHRQ, two infusion pump PSPs were selected.

What's New/Different Since the Last Report

The infusion pump was included as a new topic in the 2013 Making Health Care Safer II report. The brief review focused on implementation of smart pumps, including integrated implementation with larger safety systems such as computerized provider order entry (CPOE) and electronic medication administration records (eMARs). The report concluded that the evidence supporting efficacy of smart pumps for prevention of medical errors is limited, and successful implementation of smart pumps requires extensive planning and usually involves multidisciplinary teams.

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12.1 PSP 1: Structured Process Change and Workflow Redesign

12.1.1 Practice Description

Established workflows are often used in clinical practice to accomplish patient care goals. In the context of infusion pumps, workflow may include having a staff hand-off procedure for shift changes or requiring two nurses to validate orders, doses, and pump programming for high-alert medications.

Studies have shown that infusion pumps can contribute to inefficiencies and lead to errors. This is largely due to time-consuming, indirect patient care tasks associated with infusion pumps, such as searching for available pumps, priming tubing, manual pump programming, responding to false or unnecessary pump alarms, and managing tangled tubing.[1] Inadequate workflows for these tasks can impede communication and cause unnecessary rework, delays, or gaps in care, all which impact patient safety.[2] Organizations must also consider how new technology, such as smart pumps, affects workflow and is best implemented in order to drive toward safer use processes. Successful implementation often requires organizational commitment, a shared vision, an understanding of the risks and strengths of current processes, and a unified design that includes all systems and stakeholders.[3] In this chapter, we review current practices related to the uses of the infusion pump in clinical settings, including designing workflows, measuring clinical outcomes associated with pump use, and barriers and facilitators to implementation.

12.1.2 Methods

Two databases (CINAHL® and PubMed/MEDLINE®) were searched for "infusion pumps," "smart pumps," and related synonyms, as well as "workflow," "workflow redesign," "process change," "product recalls and withdrawals," and other similar terms, using Boolean operators. Articles included were published from 2008 to 2018. The initial search yielded 168 results. Once duplicates were removed and additional relevant articles from selected other sources were added, a total of 163 articles were screened for inclusion, and full-text articles were retrieved. Of those, nine were selected for inclusion in this review. Articles were excluded if the outcomes were not directly relevant to the PSP addressed in this review.

General methods for this report are described in the Methods section of the full report.

For this patient safety practice, a PRISMA flow diagram and evidence table, along with literature-search strategy and search-term details, are included in the report appendixes A through C.

12.1.3 Review of Evidence

Of the nine studies included in this review, four were observational studies, two were case studies, one consisted of semi-structured interviews, one was a perspective point prevalence study, and one was an online survey. The majority of the studies took place in a hospital setting; four took place outside of the United States.

Key Findings:

Outcomes

- Four studies reported medication administration errors, procedural errors, or deviations from hospital policy as clinical outcomes of workflow or process changes.
- Two studies looked at process outcomes related to pump handling; however, mixed results were found.

Implementation

- Four studies identified streamlining and standardization of process and workflows as facilitators.
- Integrating technology and workflow was found to be a facilitator, and three studies demonstrated barriers that occur when implemented infusion pump technology and processes do not align.

The included studies primarily examined medication errors and deviations from hospital policy as outcomes of process changes. However, because nearly half of the studies were observational, it is difficult to draw conclusions about the impact of implemented process changes. A summary of key findings related to process changes and workflow redesign for infusion pump use are located in the Key Findings box above. The following section reviews outcomes associated with practice changes, followed by the barriers and facilitators to implementation.

12.1.3.1 Clinical Outcomes

Four of the nine studies reported clinical outcomes, including medication administration errors, procedural errors, or deviations from hospital policy, as outcomes of workflow or process changes. Deviations from hospital policy may indicate that the established processes do not align with the natural workflow of the clinic and that a workflow change is needed to better align current practice with new infusion pump technology.

Russell et al. observed a pediatric intensive care unit (PICU) before and after workflow changes as a result of expansion and implementation of a bidirectional interface between CPOE and the pharmacy system. The researchers compared the discrepancies between medication orders and infusion pump settings, and found that the overall discrepancy rate for medications did not significantly change but the type of discrepancy did. For example, they reported that the proportion of unauthorized medications decreased from 60 percent to 4 percent, but the rate of omitted medications and errors associated with dosage significantly increased.[4] In addition, Wiseman et al. conducted a pre/post observational study in Australia and found that, as a result of implementing a requirement for clinical pharmacist annotation on medication charts, medication administration errors dropped from 16.6 percent to 8.1 percent. Subsequent adoption of smart pump technology led the error rate to further decrease to 3.9 percent.[5]

Two observational studies did not measure the impact of a process change or workflow redesign on errors but reported types and frequency of errors related to an existing medication administration process. Schnock et al. measured policy violations to assess the IV medication administration process and found that the most frequent types of infusion errors were IV labeling (60%) and tubing change policies (35%).[6] Similarly, Lyons et al. observed 16 National Health Service trusts in England and found that 47.9 percent of all infusions had at least one procedural or documentation error, of which non-compliance with hospital labeling requirements was the most common.[7]

12.1.3.2 Process Outcomes

Two studies looked at process outcomes related to pump handling. DeGraff reported that in response to a shortage of IV pumps and staff members hoarding pumps, a hospital implemented a new procedure for cleaning and restocking pumps. This process change resulted in decreasing the steps for pump handling from 26 to 8.[8] The results of process change were more mixed in a study by Chaturvedi et al., in which a hospital integrated its electronic health records (EHRs), CPOE, smart pumps, and barcode-assisted medication administration (BCMA) systems, and engaged in multiple efforts to standardize workflows. The integrated system significantly reduced the amount of time required by nurses to program medications; however, nurses reported that their overall workload did not decrease and that there was an increase in the number of computer steps required to administer medications.[9]

12.1.3.3 Economic Outcomes

Biltoft and Finneman measured cost savings of integrating smart pumps with electronic medical records (EMRs) after determining the study hospital was losing revenue due to a lack of sufficient documentation to support the billed charges or missing documentation, specifically stop times, in the medication administration record for outpatient infusions. The researchers found that implementation of the integrated smart pump-EMR provided accurate start and stop times which reduced both mean lost charges for infusions (from 11.9% to 7.4%) and lost revenue (from $980,000 to $610,000).[10]

12.1.4 Implementation

12.1.4.1 Summary of Evidence on Implementation

Changing processes or redesigning workflows for infusion pumps can be a complex undertaking that includes a variety of interventions. The studies included in this review implemented or analyzed process changes that were specific to the needs of the hospital or infusion pump system and may not be generalizable. This section reviews some of the common facilitators and barriers that emerged in relation to implementing process changes or redesigning workflows to improve infusion pump use.

12.1.4.2 Facilitators and Barriers

12.1.4.2.1 Facilitators

Standardization and streamlining of processes and workflows were identified as main facilitators of optimal infusion pump use across multiple studies. For example, DeGraff found that a hospital was able to significantly improve utilization of IV infusion pumps by streamlining its workflow for cleaning and restocking pumps.[8] Biltoft and Finneman streamlined nursing workflows by reconfiguring rooms so that infusion pumps and EHR computers could be accessed at the same time, which led to more accurate infusion documentation.[10] In addition, Schnock et al. note that by reviewing existing policies, the study team recognized the benefits of using standardized tubing labels to indicate when a nurse should change tubing.[6] Finally Chaturvedi et al. found that hospital leaders viewed standardization of nursing workflow as extremely beneficial because it was perceived to reduce the frequency of nursing workarounds that could cause patient harm.[9]

The included studies also highlighted the importance of integrating technology and workflows. Pinkney et al. noted that implementation of smart pumps should be viewed as part of a larger safety initiative rather than just a technology upgrade and that in order to be successful, implementation should focus on design of workflows. For example, they found that implementing design-oriented solutions that constrain users to follow the preferred workflow, such as defaulting users into using the drug library, helps ensure users employ the safety features.[11] Similarly, Chaturvedi et al. concluded that implementation of an IV clinical integration system is not only a technology intervention but requires workflow changes to be successful.[9]

In addition, engaging multiple members of the care team in workflow redesign is an important facilitator. For example, Wiseman et al. found that clinical pharmacists play a key role in reducing error rates and should be consulted when configuring workflows.[5] Russell et al. found that after the PICU was relocated and expanded, pharmacist and dietician presence on rounds increased, resulting in greater collaboration between them and those responsible for ordering medications. This collaboration helped reduce the number of reorders.[4]

12.1.4.2.2 Barriers

Lyons et al. noted that in some cases procedural deviations are not representative of inadequate care practices but rather demonstrate a poor fit between hospital policy and everyday practice. If workflows do not align with new technology or policies are implemented that are not compatible with natural workflows, then errors or workarounds can occur that impact patient safety. For example, they found that staff reported deliberate deviations that would benefit patients but conflicted with official rules and formal procedures, such as giving patients fluids that had not yet been prescribed because a doctor was unavailable.[7] Schnock et al. found that information such as infusion start time, which was necessary to document on paper labels, was no longer needed after implementation of CPOE, eMAR, and BCMA, since it was automatically entered into the system. This example illustrates that when new technology is implemented, processes such as documentation workflows must be reevaluated for relevance.[6] Furthermore, Russell et al. noted that prior to implementation of a bidirectional interface between CPOE and the pharmacy system, if a provider requested a new urgent medication, the pharmacist could deliver the medication but would be unable to reconcile the order so it appeared as an unauthorized medication. In this case, implementing the new system rectified the misalignment between technology and the established workflow by allowing pharmacists to immediately reconcile verbal orders from physicians.[4]

Staff buy-in and hospital resources were also identified as barriers to process changes. Chaturvedi et al. reported challenges gaining buy-in from nurses to adopt workflow changes and noted that frontline staff often expressed concerns regarding the patient safety implications of workflow changes.[9] Iacovides et al. also noted that when implementing infusion pump technology, organizations need to ensure that adequate infrastructure and resources are available, and that the affected staff believe that the change is worth the time and money required.[12]

12.1.4.3 Resources To Assist with Implementation

As a result of a 2008 summit, the ISMP published Proceedings from The ISMP Summit on the Use of Smart Infusion Pumps: Guidelines for Safe Implementation and Use. A second summit was held in 2018, and the guidelines are currently being updated. The revised and expanded guidelines are designed to support optimization of smart pump technology and assist organizations in transition to smart pump interoperability. In 2010, the FDA undertook the Infusion Pump Improvement Initiative to support benefits of infusion pumps while minimizing risks. The FDA also has a list of infusion pump risk reduction strategies organized by type of user.

12.1.4.4 Gaps and Future Directions

There is strong evidence describing the frequency and type of medication and procedural errors associated with infusion pump use, however, there is limited research on workflow and process changes that can be implemented to address those errors. More implementation studies are needed to understand best practices for reducing errors and improving infusion pump use through workflow and process changes.

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12.2. PSP 2: Staff Education and Training

12.2.1 Practice Description

The literature shows that inadequate training is often associated with knowledge and rule-based mistakes when using infusion pumps.[1] These medication errors can occur when staff are inexperienced, including being unfamiliar with the medication, environment, procedure, or equipment. In addition, lack of training can lead to overriding of smart pump safety features erroneously. Although smart pumps can be a beneficial tool to reduce medication errors attributed to manual programming, using the embedded drug libraries and DERSs is not mandatory. The literature shows that nurses commonly bypass the safety features because the drug library parameters are not customized for their patient population, it takes too much time to program the pumps, and there are too many alarms.[2] To prevent overriding safety features and programming errors, some hospitals invest in initial and ongoing staff training on the correct use, maintenance, and monitoring of smart pumps. Hospitals may also implement standard procedures for pump management and provide education on the use of the standardized protocols.

The FDA recommends providing training and educational activities for all employees designed to promote the safe use of infusion pumps, including drug library usage, as a risk-reduction strategy for facility administrators and managers.[3] In addition, the ISMP, in its draft guidelines from the ISMP National Smart Infusion Pump Summit in 2018, states that organizations should establish a standard approach for staff training and ensure that the education provided emphasizes the intended safety benefits.

This section reviews studies of education and training programs implemented to address infusion pump errors by examining clinical and process outcome measures, as well as barriers and facilitators to implementation.

12.2.2 Methods

Two databases (CINAHL® and PubMed/MEDLINE®) were searched for “infusion pumps,” “smart pumps,” and related synonyms, as well as “in-service,” “staff education,” “staff training,” and other similar terms, using Boolean operators. Articles included were published from 2008 to 2018. The initial search yielded 104 results. Once duplicates were removed and additional relevant articles from selected other sources were added, a total of 107 articles were screened for inclusion and full-text articles were retrieved. Of those, 12 were selected for inclusion in this review. Articles were excluded if the outcomes were not directly relevant to the PSP addressed in this review, the article was out of scope, or study design was insufficiently described.

General methods for this report are described in the Methods section of the full report.

For this patient safety practice, a PRISMA flow diagram and evidence table, along with literature-search strategy and search-term details, are included in the report appendixes A through C.

12.2.3 Review of Evidence

A summary of key findings related to staff education and training is located in the call-out box. The following section reviews the studies in more depth. Of the 12 studies included in this review, 5 were

performance or quality improvement initiatives. Other study designs included a longitudinal study, observational study, snapshot audit, and randomized controlled trial. Ten of the 12 studies took place in a hospital setting, two of which were pediatric hospitals. Two studies took place in a simulation laboratory used for training. Three of the studies took place outside the United States.

To evaluate the impact of implementing staff education and training on the correct use, maintenance, and monitoring of infusion pumps, the studies measured clinical outcomes as well as process outcomes related to compliance and use of safety features. The review's key findings are located in the box to the right.

Key Findings:

Outcomes

- Four studies measured clinical outcomes for the impact of investing in education on the correct use, maintenance, and monitoring of smart pumps, including three that reported a decrease in medication errors and one that reported a decrease in the number of adverse drug events.
- Two studies found an increase in nurses' adherence to using the medication safety software library as a result of education.

Implementation

- Five studies identified the type and content of education provided as facilitators.
- One of the studies noted that time and energy constraints on nurse educators can be barriers to implementing large hospital-wide education programs.

12.2.3.1 Clinical Outcomes

Of the 12 studies, 4 reported clinical outcomes for the impact of investing in education on the correct use, maintenance, and monitoring of smart pumps. Measured clinical outcomes included the number of medication errors, severe harms adverted, and adverse drug events.

A study by Ferguson et al. examined implementation of mandatory training over 4 months on the proper usage of patient-controlled analgesia pumps for all registered nurses (RNs) who use the pumps. The study found that the number of pump errors reported over 3 months significantly decreased from eight prior to the intervention to one after the intervention, addressing the primary cause of medication errors in the 22-unit hospital.[4] Van der Sluijs et al. used a Lean approach based on feedback and training to implement a fixed, dedicated moment of time to double-check medications and a standard operating procedure for changing syringe pumps. The Lean philosophy is a quality improvement method that aims to improve processes and reduce errors by paying attention to little problems. The implementation was communicated to clinical staff through lessons and instructions, and the authors found that over 18 months, the overall percentage of medication errors (the percentage of syringes used with a medication error) dropped from 17.7 percent to 2.3 percent.[5] In addition, Giuliano measured the impact of user training in a simulation lab on the frequency of programming use error for three IV smart pumps and found that use errors decreased from 30 percent to 7 percent, 17 percent to 3 percent, and 8 percent to 1 percent. Giuliano also found that programming time was significantly shorter after user training.[6]

One study measured different clinical outcomes of proper infusion pump usage: the number of severe harms adverted and adverse drug events. Orto et al. sought to increase compliance with use of the smart pump specifications by assigning nurse champions to conduct monthly educational sessions with RN staff, both individually and in groups, to ensure that they were using the smart pumps and their drug library parameters. The authors found that the aggregate number of severe harms averted (defined as high risk drugs being programmed by the nurse 2.5 times or greater than recommended) per 1,000 infusion starts over 6 months decreased from 0.68 pre-intervention to 0.44 post-intervention, indicating there were fewer episodes of severe infusion harms. In addition, the number of adverse drug events more severe than level 2—defined as events that reach the patient and require intervention and monitoring—decreased from four to one from pre-implementation to post-intervention.[7]

12.2.3.2 Process Outcomes

Studies examining the impact of implementing education and training on proper usage of infusion pumps measure compliance with pump technology protocols and adherence to using safety software. In a study by Gavriloff, researchers implemented staff education focusing on the correct use of the safety software and the benefits of preventing medication errors as part of a multicomponent intervention. The goal of the education program was to improve nurses' adherence to using the medication safety software drug library created by the healthcare organization. Just 1 month after it was implemented, the adherence rate had increased from 25 percent at baseline to 68 percent. The adherence rate further increased to 85 percent after the Chief Nursing Office sent a follow-up communication encouraging nurses to use the medication safety software.[8] In addition, Orto et al. measured compliance with use of the drug library in smart pumps in a hospital where not using the drug library constituted noncompliance with hospital policy. They found that, after implementation of a nurse-led smart pump champions program, compliance among RNs significantly increased from 85 percent to 92 percent. These gains were sustained post-intervention with a compliance of 92.9 percent and 93.3 percent at 3 and 6 months, respectively.[7]

One study examined the impact of an education intervention on the use of smart pump safety features. In a pre-intervention survey of nurses, Herring et al. found that 88.6 percent of respondents reported agreeing or strongly agreeing that training and education were adequate, and 82.8 percent agreed or strongly agreed that they knew how to use the drug library. However, 44 percent of the open-response comments requested additional training on the safety features. After implementing an education program that included a mandatory active-learning practical-skills laboratory and an optional education presentation that reviewed evidence of improved patient safety when smart pump safety features are fully used, the authors found that use of the pump mode with all safety features enabled increased from 5.5 percent to 30.5 percent.[9]

12.2.3.3 Economic Outcomes

Of the 12 studies, only 1 study measured cost outcomes. Orto et al. calculated potential cost avoidance, defined as costs that would have been incurred if the severe harms had not been averted. The study found the costs avoided because severe harms were averted came to $367,500 at the end of the intervention period compared to $612,500 6 months before the intervention. The lower cost is associated with lower numbers for severe harms averted due to the use of smart pumps.[7]

12.2.4 Implementation

12.2.4.1 Summary of Evidence on Implementation

Although limited evidence is provided in this review, common themes regarding implementation of an education intervention emerged. This section reviews some of the facilitators and barriers to implementing staff training on the correct use, maintenance, and monitoring of smart pumps.

12.2.4.2 Facilitators and Barriers

12.2.4.2.1 Facilitators

The type and content of education provided were identified as important facilitators to successful implementation. For example, Herring et al. found that education from the device manufacturer alone may be insufficient and that implementing a hands-on training targeting identified obstacles was essential to increasing use of safety features.[9] Similarly, Nemeth et al. found that in order to be most

successful, the training program should include opportunities for participants to apply learning through discussing case examples. They also found that training should provide information about the most relevant smart pump functions and the potential challenges nurses may encounter in using them. Virtual training systems have also been shown to facilitate learning, although the results are mixed.[10] In a study by Luctkar-Flude et al., participants who completed an online virtual IV pump learning module reported that the module enhanced their knowledge of programming; however, most students did not feel it increased their ability to program certain types of infusions.[11] Quattromani et al. compared use of a traditional training method with a faculty member to use of an interactive smart pump training app and found no significant difference in outcomes related to medical knowledge, performance, or learner confidence.[12]

In addition to the type of training, the choice of trainer can be a facilitator. For example, Orto el al. implemented a nurse champion-led group to improve smart pump compliance due to the success their hospital had in the past with this type of intervention.[7] Finally, Gavriloff found that training that focuses on “why” smart pumps are used instead of just “how” to use smart pumps is important to increase adherence. By understanding the safety software, nurses are able to provide ongoing evaluation on needed revisions and refinements.[8]

12.2.4.2.2 Barriers

Limited knowledge transfer and constrained hospital and staff resources were reported as potential barriers to implementation. For example, Lee found that when nurses move to different wards, they are often exposed to new devices on which they have not been trained.[13] In addition, Ferguson et al. note that after nurses are trained, they may not retain competency on use of a particular type of smart pump if they commonly use multiple types of pumps or if they infrequently use any pumps. Furthermore, Ferguson et al. note that establishing hospital-wide education programs can be a significant undertaking for staff development departments, and that the time and energy constraints on nurse educators should be carefully considered and planned.[4] Carayon et al. highlight the importance of planning by noting that a lack of attention devoted to the implementation planning process resulted in nurses reporting more negative perceptions of usefulness of information and clarity of training materials 6 weeks and 1 year after the time of the initial training.[14]

Resistance to culture change was also identified as a potential barrier. Subramanyam et al. found that, despite being educated on the use of standardized pump programming, nurses were resistant to a culture change from the old processes to a new two-person verification process.[15] Orto et al. noted that they implemented a nurse-led program focusing on promoting compliance, partnering with pharmacists, and supporting manual audits to help create a culture of safety.[7]

12.2.4.3 Gaps and Future Directions

Although the use of smart pump technology has increasingly become standard practice in hospitals, there is limited evidence on best practices for education and training on the proper usage of smart pumps. More research is needed to understand why clinicians commonly bypass smart pump safety technology and what type of training should be implemented to limit medical errors.

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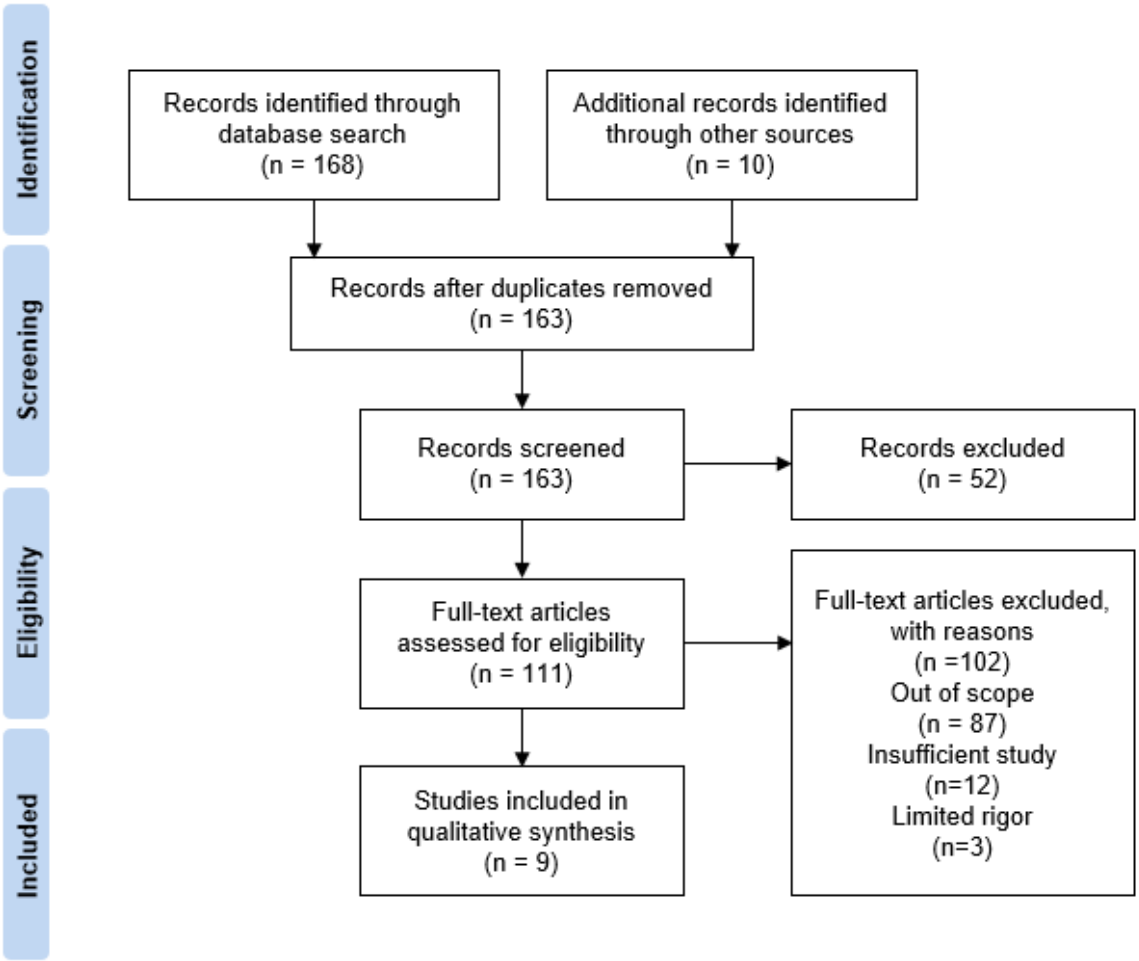
Conclusion and Comment

The two patient safety practices reviewed in this chapter aim to reduce medication errors by implementing initiatives to improve the use, maintenance, and monitoring of infusion pumps. The review of evidence shows that protocols and workflows are integral to proper technology use and therefore should be carefully considered when implementing new infusion pump technology. The studies included in this review provide support for streamlining and standardizing workflows. However, more implementation studies are needed to better understand the impact of workflow changes and best practices for effective integration of processes and infusion pump use. The evidence also shows support for providing education and training on infusion pumps to promote safe use. In these studies, the type and content of education provided were highlighted as facilitators, while limited knowledge transfer and resistance to culture changes were identified as barriers.

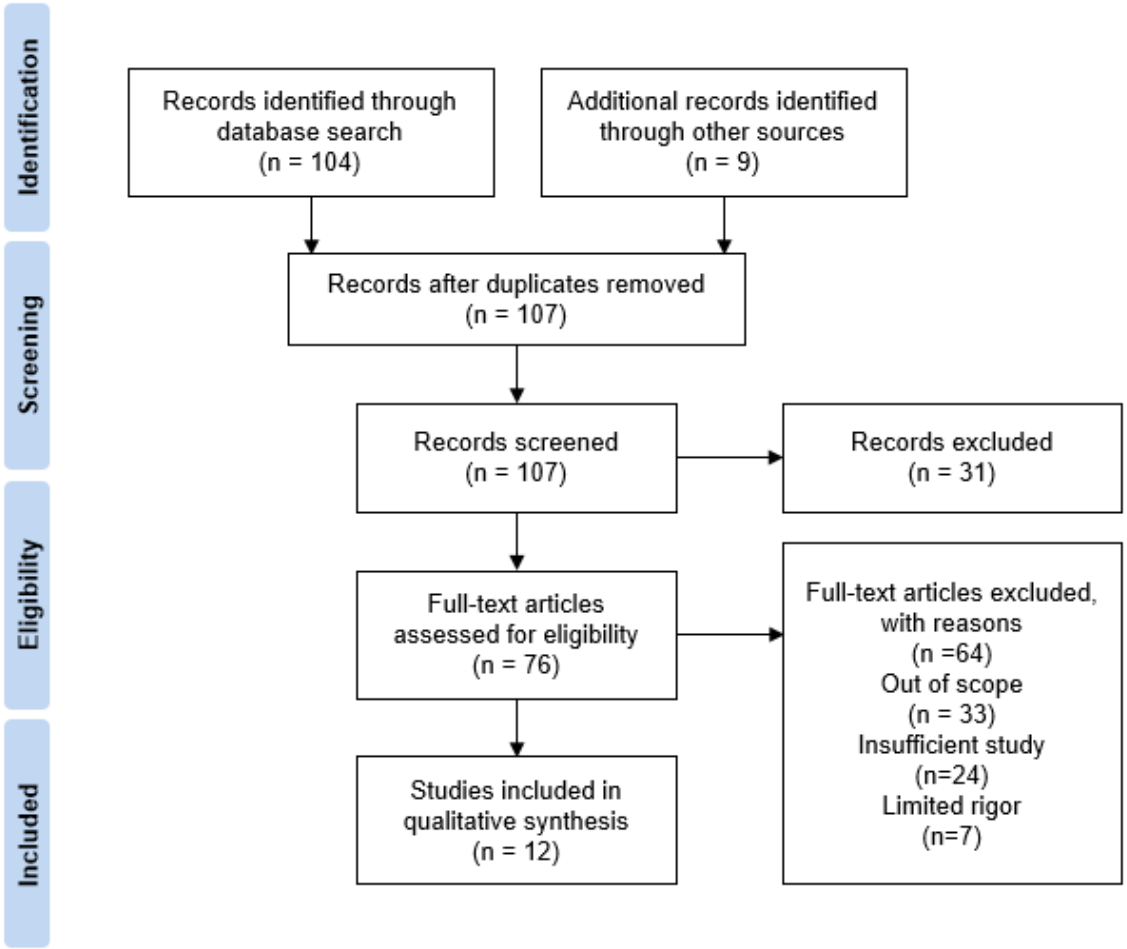
Appendix A. Infusion Pumps PRISMA Diagrams

Figure A.1: Infusion Pumps, Structured Process Change and Workflow Redesign—Study Selection for Review



PRISMA criteria described in Moher D, Liberati A, Tetzlaff J, et al. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med. 2009 Jul 21;6(7): e1000097. doi:10.1371/journal.pmed1000097.

Figure A.2: Infusion Pumps, Staff Education and Training—Study Selection for Review



PRISMA criteria described in Moher D, Liberati A, Tetzlaff J, et al. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med. 2009 Jul 21;6(7): e1000097. doi:10.1371/journal.pmed1000097.

Appendix B. Infusion Pumps Evidence Tables

Table B.1: Infusion Pumps, Structured Process Change and Workflow Redesign—Single Studies

Note: Full references are available in the Section 12.1 reference list.

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)
Biltoft and Finneman, 2018[10]	Hospital implemented smart pump- electronic medical record (EMR) interoperability to decrease opportunities for errors by reducing manual clinician keystrokes needed to program an infusion. Conducted workflow analyses prior to implementation. The team made necessary changes to streamline workflow, such as reconfiguring rooms so that infusion pumps and EMR computers could be accessed at the same time for the most accurate infusion documentation. In addition, implemented a double-check to ensure that all medication identifiers populated the correct drug library and corresponded to those in the EMR. This helps streamline nursing workflow, especially when there are patient transfers between units.	Case study	Hospital (286 beds) within a regional health system. United States	Pre-population of infusion parameters reduced manual keystrokes by 86%. Compliance with using interoperability technology averaged 70-80% in the first 7 months. Rate of appropriate entry of patient identification information by pump users increased from 35.5% to 81%. Mean monthly number of alert overrides decreased by 20%.	Not provided	Pharmacist-led implementation of smart pump-EMR interoperability led to measurable improvements in intravenous (IV) medication safety and improved accuracy, timeliness, and efficiency of IV infusion documentation.	High—case study

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)
Chaturvedi et al., 2019[9]	Hospital implemented intravenous clinical integration (IVCI), which links EMRs, computerized physician order entry (CPOE), smart pumps, and bar code medication administration systems in order to reduce human errors caused by manual documentation. During the planning process, hospital leaders discovered significant variation in nursing workflows for IV administration and engaged in multiple efforts to standardize workflows.	Qualitative description of hospital's IVCI implementation. Conducted semi-structured interviews with 33 informants: 4 pharmacists, 8 IT personnel, 10 frontline nurses, 4 nurse trainers, and 7 hospital leaders. Researchers observed nurse IVCI training and nurses on five units.	Large nonprofit academic medical center (886 beds), United States	Hospital leaders viewed standardization as extremely beneficial because it was perceived to reduce the frequency of nursing workarounds that could cause patient harm.	Nurses often forgot to validate infusion completion times, which led to large errors in recorded infusion volumes. Although the EMR automatically enters infused volumes into patients' charts, nurses are required to manually validate completion times. IVCI significantly reduced the amount of time required by nurses to program the pumps but did not decrease their workload overall. Many nurses reported that IVCI increased the number of computer steps required to administer medications. There were challenges gaining buy-in from nurses to adopt workflow changes, and frontline staff expressed concerns regarding safety of workflow changes. Since not all units had IVCI, moving patients required special procedures.	IVCI implementation is not just a technological intervention, but also requires workflow standardization in order to be successful.	Moderate

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)
DeGraff, 2013[8]	In response to a shortage of IV pumps and staff members hoarding pumps, the team created a new procedure for cleaning and restocking pumps on floors. This allowed staff to easily see when the supply fell below a set minimum and pumps needed to be restocked.	Case study	Five hundred seventy-bed regional referral center and teaching hospital, United States	New process reduced pump handling steps from 26 to 8. Pumps were available when needed 94% of the time, compared to 28% before implementation.	Not provided	Hospital dramatically improved utilization of IV infusion pumps by streamlining their workflow.	High—case study
Iacovides et al., 2014[12]	Survey investigated the extent to which standardization of infusion devices has occurred.	Online survey sent to device managers and trainers within National Health Service (NHS) organizations. Forty-five respondents participated in study.	Staff were involved within 49 U.K. organizations representing 120 hospitals. United Kingdom.	A high level of standardization was reported. (Only 4% reported there was no standardization at all.)	Reasons for not using dose error reduction software included time required to implement and train staff, and not being able to standardize across the entire site.	To implement technology, organizations need to overcome challenges, including existing device contracts, infrastructure and resources available, required time and investment, and complications related to lack of standardization.	Moderate

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)
Lyons et al., 2018[7]	Observers compared medications being administered against the prescription and local policies/guidance. Recorded any deviations from a prescriber's written or electronic medication order, the hospital's intravenous policy and guidelines, or the manufacturer's instructions.	Point prevalence observational study. Data were collected on 1,326 patients who were administered 2008 infusions.	16 NHS trusts, England.	Most (90%) of the observed errors were considered unlikely to cause harm. One site responded to poor compliance with documentation of medication administration by purchasing handheld computers to allow staff to access electronic records in closer proximity to patients.	Nearly 48% (47.9%) of infusions had at least one procedural or documentation error. Non-compliance with hospital requirements for labeling infusion administration sets was most common. Discrepancy rates were higher in infusions delivered using smart pumps compared to those without safety features. Differences were linked with policy requirements. Error rates were similar.	Procedural deviations may not always represent poor practice, but rather poor fit between policy and everyday practice.	Moderate

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)
Pinkney et al., 2010[11]	Conducted 3 experiments to quantify the impact of infusion pump type, smart pump design, and training on nurses' ability to safety deliver IV medications.	Conducted 3 observational studies.	Usability lab that simulated an inpatient unit, Canada.	Smart infusion systems were found to statistically reduce the rate of medication errors. Users programmed almost all infusions within a drug library when the pump workflow either defaulted them into the drug library or prompted them to use the drug library.	Soft limit warnings had no impact on preventing errors since nurses simply overrode them.	Smart pumps that rely on users actively engaging the drug library are less preferable to those that encourage/require nurses to enter into the drug library. Supporting and constraining users to follow the preferred workflow is a design-oriented solution that can help ensure users employ the safety features of the smart pump. Smart pump implementation should be viewed as part of a larger safety initiative, not just technology replacement. Implementation should focus on design of workflows and environments.	Moderate

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)
Russell et al., 2015[4]	Study examined the impact of a bidirectional interface between CPOE and pharmacy systems on the frequency and types of discrepancies between orders for medication and intravenous fluid (IVF) infusions and pump settings. Pediatric intensive care unit (PICU) underwent expansion and relocation that caused changes in workflow.	Uncontrolled before and after study using a prospective, observational design. Compared proportion of discrepancies with results of a study conducted by the authors in 2007.	Children's hospital, PICU (72 beds), United States	Overall discrepancy rate did not change; however, type of discrepancy changed. Unauthorized medications decreased from 60% in 2007 to 4% in 2010. Bidirectional interface allowed pharmacist to immediately reconcile verbal orders. Change in workflow on rounds was likely responsible for decrease in discrepancies for parenteral nutrition subgroup medications. In the new environment, pharmacy and dietary presence on rounds increased, resulting in greater collaboration among pharmacists, dieticians, and the providers responsible for ordering, preventing the number of reorders that previously had occurred.	Fifty-four of 303 (18%) observations of medication infusions revealed order programming discrepancies, while 46 of the 152 (30%) observations of IVF revealed order-infusion pump discrepancies. There was significant increase in proportion of omitted medications and wrong dose. Change in workflow was suspected to be the reason for the increase.	Analysis suggests that the observed decreases in discrepancies were not solely attributable to the technology. Workflow and other factors had an impact on the observed changes.	Moderate

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)
Schnock et al. 2017[6]	Objective of the study was to investigate the frequency and types of IV medication errors associated with the use of smart pumps. Measured policy violations to assess the IV medication administration process.	Prospective point prevalence approach to capture errors associated with smart pump administered medications. Evaluated 478 patients receiving and/or prescribed IV medications.	Ten hospitals: seven academic medical centers and three community hospitals, United States		Violations of IV labeling and tubing change policies were the most frequent error types (60% and 35%, respectively). Infusion rate errors were the leading type of serious medication error.	High rate of errors was found in the administration of IV medications despite the use of smart pumps, but relatively few were harmful errors. In reviewing labeling policy, researchers found that some information needed prior to implementation of electronic records is no longer necessary. Team recognized the benefits of using standardized tubing labels to distinguish when nurse should change tubing. Results highlight the importance of reviewing existing practices and policies when implementing technologies such as smart pumps.	Moderate
Wiseman et al., 2018[5]	Implemented clinical pharmacist annotation on medication charts (i.e., completing missing information in infusion medication orders) and adopted smart pump technology. Smart pump adoption involved a 6-month development phase.	Semi-structured observational study conducted over four periods, pre and post intervention: July 2009, July 2011, April 2012, and June 2014. Over 5 years, 16,866 patients and 2,599 infusions were observed.	Four hundred fifty bed tertiary referral hospital, Australia.	After implementing pharmacist annotation, errors reduced from 16.6 to 8.1%. Implementation of smart pumps resulted in a reduction from 8.1 to 3.9%.	Not provided	Results suggest clinical pharmacists play a key role in reducing rate of errors.	Moderate

Table B.2: Infusion Pumps, Staff Education and Training—Single Studies

Note: Full references are available in the Section 12.2 reference list.

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)
Carayon et al., 2010[14]	Nurses attended training sessions on smart intravenous (IV) pump use that occurred the week before pump implementation. Training consisted of hands-on skills training provided by nurse super-users and an optional computer-based training module.	Data were collected in three longitudinal surveys: pre-implementation of smart IV pumps and 6 weeks and 1 year post-implementation. Sample of nurses that responded to the surveys: pre-implementation survey (n=190, response rate: 32%), 6-week-post-implementation survey (n=322, response rate: 31%), and 1-year-post-implementation survey (n=399, response rate: 38%).	Academic hospital. United States	Overall, nurses' acceptance of the smart pump technology was positive and improved over time. Respondents rated the information they received about pump implementation as more useful before implementation than 6 weeks after. "Learning to operate the pump" became easier 1 year after implementation, compared to either before or 6 weeks after implementation.	Respondents reported that the training materials were more confusing in the 6-week and 1-year-post-implementation surveys.	Nurses reported more negative perceptions of the smart IV pump implementation process (e.g., usefulness of information received about pump implementation and clarity of training materials) 6 weeks after implementation, compared to what they perceived before implementation. This suggests more attention should have been devoted to the implementation process, especially regarding information and training materials.	Moderate

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)
Ferguson et al., 2010[4]	Hospital was following all the patient-controlled analgesia (PCA) guidelines recommended by USP except for annual retraining staff on the proper usage. Established mandatory training by nurse educators of registered nurses (RNs) who used PCA pumps. Participants were required to return within 1 hour of the review to demonstrate proper programming of a preprinted order set into the PCA pump without any assistance from the educator. All staff members were required to complete an online module and test.	Quality improvement (QI) project. Examined PCA errors in the pre-intervention and post-intervention periods to determine effectiveness of mandatory training. Pre-intervention data were collected from June to August 2006 and post-intervention from June to August 2007. The educational intervention occurred from January to April 2007.	Small Midwestern hospital with 22 patient care units. United States	Significant decrease from eight errors reported in the pre-intervention period to one in the post-intervention period.	Not provided	Results show that the educational intervention was effective in deceasing PCA pump errors. Adding additional mandated education programs must be carefully considered. Combining QI data with education initiatives can help provide objective measures that resources are well spent.	Moderate

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)
Gavriloff, 2012[8]	Staff education focusing on correct use of the safety software and the benefits of preventing medication errors. Super-user training for medical safety champions and education on the patient care units for nurses.	Performance improvement project using plan, do, study, act (PDSA) methodology.	359-bed pediatric hospital. United States	Within 2 months, 100% of RN staff were educated and the content was fully incorporated into nursing orientation. Adherence rate was 68% 1 month after staff education was completed, an increase from 28% at baseline. After the chief nursing officer sent a followup email encouraging nurses to use the medication safety software, adherence increased to 85%. In the following months, adherence continued to remain above 85%. Education on the smart pumps allowed for any safety concerns to be easily communicated and provided closed-loop communication with the nurses.	Not provided	The combined use of staff education, improving communication, programming strategies, medication safety champions, adherence monitoring, and technology acquisition increased nursing adherence to a rate consistently above 85%. Staff education that focuses not only on the “how” to use the smart pumps but also on the “why” it is used is important to increase medication safety software adherence.	Moderate

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)
Giuliano, 2015[6]	Study aimed to measure the impact of user training on programming times and use errors. User training consisted of a brief training, according to manufacturer's instructions, on the IV medication tasks being used in the study.	Pilot study using within-subjects design. Study measured differences in programming times and frequency of programming errors for three IV smart pumps. Fifteen critical care nurse participants completed five programming tasks in a simulation laboratory.	Study participants were recruited from Boston-area hospitals. Data collection took place in a simulation laboratory.	Programming time for all five tasks across the three pumps was shorter after the user training. Majority of the tasks had a statistically significant time difference. The percentage of use error decreased after user training for all three IV smart pumps: pump A, 30% to 7%; B, 17% to 3%; and C, 8% to 1%.	Not provided	Findings support the value of proper user training in helping clinicians learn to operate the IV smart pumps in a more time-efficient manner and make fewer use errors.	Moderate

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)
Herring et al., 2012[9]	Hospira Plum A+ smart pumps were implemented, and education about safety feature use was provided to bedside patient care nurses at program initiation through online computer modules designed by manufacturer. The researchers surveyed nurses and identified education and training as an obstacle to smart pump utilization. Over a 6-week period, a pharmacist provided education to target identified obstacles. Active learning, practical skills lab mandated for all institutional nurses. The skills lab included hands-on scenarios for programming, troubleshooting tactics, and hypothetical situations. Cardiovascular nurses were offered an optional educational presentation on use of safety features.	QI cross-sectional study. Rates of use of the delivery modes were captured through a wireless database. Nurses were surveyed to identify obstacles in the cardiovascular service clinical care areas; 35 of 60 nurses (58%) responded. Based on survey results, interventions were designed to target education and burden of use.	Academic center hospital (689 beds). United States	The majority of survey respondents agreed or strongly agreed that training and education were adequate, the drug library enhanced patient safety, and they knew how to use the drug library. Use of “with limits” mode (when all safety features are applied) increased from 5.5% to 30.5% after educational interventions.	Of the free-text survey comments, 44% requested additional training on the safety features.	Survey results indicate that education from the manufacturer alone may be insufficient. Supplemental hands-on training significantly increased safety feature use. Overall use was still low. One explanation may be related to the procedure for smart pump data entry.	Moderate
Lee, 2010[13]	Audit and response to findings, including standardized settings and controls to ensure consistent operation of pumps.	Conducted an audit and then developed coordinated approach in response	Two acute hospitals within a National Health System Trust, South Wales.	A series of training days and standardized practices were developed to ensure operators had a clear understanding of the limitations and correct procedures for setting up these devices.	Audit showed staff were being deployed to other wards and exposed to new devices they had not been trained to use.	Using a coordinated approach to replace infusion pump devices and setting short and long-term goals can be an effective way to manage risks.	Moderate

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)
Luctkar-Flude et al., 2012[11]	Online virtual IV pump educational module for undergraduate nursing students. Participants assigned to the experimental group were required to complete the virtual IV pump educational module.	Twenty-six nursing students in control group and 17 in the experimental group All participants completed an IV Pump Skills Self-Confidence Survey. Experimental group completed a Virtual IV Pump Educational Module Satisfaction Survey. Lab research assistant evaluated student performance of IV pump skills.	Academic hospital, Canada.	Majority of students felt the module enhanced their knowledge of programming the IV pump and felt the virtual IV pump module was convenient and easy to use. Overall, students in the experimental group had higher performance scores than those in the control group; however, they took longer to perform skills. Difference was not statistically significant. Experimental group participants scored significantly higher than control group participants in programming a continuous medication infusion.	Most students did not feel the module enhanced their ability to program a basic infusion, secondary medication bolus, or continuous medication infusion.	Findings suggest there is value in providing virtual online education module in the nursing skills lab.	Moderate

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)
Nemeth et al., 2014[10]	Research to understand the effect of introducing a smart pump through a naturalistic look into the experience of those who use it.	Mixed-methods field study combining 9 hours of observation, formal interviews, and Cognitive Task Analyses Sample: 9 nurses, 1 biomed engineer, 1 pharmacist.	Midwest tertiary care hospital. United States	The study found that, in the opinion of nurse study participants, the implementation of the smart pump has so far been a substantial success.	The research team found that there is a need for further investigation into system, performance, and organizational factors that affect nurses' understanding of how the smart pumps operate.	In training, nurses should hear information about the most relevant functions and potential challenges that they may encounter, and have opportunities to apply learning through case examples.	Moderate
Orto et al., 2015[7]	Study aims: (1) develop a nurse-led smart pump champion group and (2) revise existing protocol on IV therapy to integrate use of smart pumps. Two nurse directors trained the champion group to educate coworkers. Nurse champions in each unit conducted monthly education sessions. Over the 6 months of intervention, the champion group provided education to registered nurse (RN) staff individually and in groups to ensure that all RNs were using the smart pumps and associated drug libraries.	QI project: Single cohort pre/post design. 600 direct-care RNs.	Fourteen nursing units in a southeastern community hospital. United States	Overall hospital compliance rate post-implementation was significantly improved (increase from 83.5% to 92%). Costs avoided because severe harms were averted were $367,500 at the end of the intervention period compared with $612,500 6 months before the intervention. Severe harms averted dropped from 0.68 to 0.44 post-implementation.	Not provided	Development of a nurse-led champion program led to a significant improvement in compliance and decrease in number of severe harms. Nurse managers created a culture of safety and coached staff who were not compliant with smart pump drug library use.	Moderate

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)
Quattromani et al., 2018[12]	Study objective was to determine if the smart pump app is an effective and engaging educational tool for nursing students compared to existing traditional training methods. Traditional training consisted of small groups of students with one faculty member going over smart infusion pump training using a single smart infusion pump device per two students. The interventional group training consisted of small groups of students each using the mobile app smart pump training on a tablet. The smart pump app is an interactive self-contained learning encounter built on a mobile platform and designed for nurses. The app takes the students through each step of smart pump programming and allows for interactive trial and error,	Randomized controlled trial Students were randomized into either the traditional group or the intervention app group. Eighty-seven nursing students were assigned to the traditional group and 94 to the app group.	Large urban school of nursing simulation center in the Midwest. United States	Participant feedback on the app was overall positive, and 70.2% strongly agreed or agreed the app was easy to use.	There was no significant difference in outcomes of medical knowledge, simulation performance, and learner confidence. Students gave neutral ratings to whether they would like to use the tablet app teaching method more frequently and whether they will feel more comfortable at a patient's bedside as a result of using the app.	Study did not find significant differences in learner-centered outcomes or performance measures between the traditional teaching methods and app group.	Moderate

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)
Subramanyam et al., 2016[15]	Educated anesthesiologists and certified registered nurse anesthetists (CRNAs) who regularly provided anesthesia about the importance of safety checks to reduce medication errors. Educated stakeholders with a job aid (anesthesiologists, CRNAs, RNs) about the use of standardized pump programming, and RNs about anesthesia medications.	QI project using PDSA cycles.	Urban tertiary pediatric academic care center, anesthesia department. United States	Implementation of two- person verification resulted in >90% medication programming being double-checked prior to administration.	Cultural resistance to changing to two-person verification process. This challenge was discussed at departmental meetings.	A standardized team-based approach decreased the number of medication errors by early identification of programming errors.	Moderate
Van der Sluijs et al., 2019[5]	Implemented standard protocols on how to change syringes and a fixed, dedicated moment to perform double-checks. Used a Lean coach, a formally trained employee who supports Lean projects in hospitals, to support efforts.	Pre-post observational study; used Lean philosophy. Measured impact of interventions by performing unannounced sequential audits.	Tertiary care university hospital, 32-bed mixed medical surgical intensive care unit (ICU), Netherlands.	Over 18 months, the overall percentage of errors dropped from 17.7% to 2.3%.	Not provided	Results show a Lean approach is successful in reducing the number of errors with the administration of medication with syringe infusion pumps in the ICU.	Moderate

Appendix C. Infusion Pumps Search Terms

Method	Search	Search String for: CINAHL	Search String for: MEDLINE
Search 2008-Present, English Only MedLine Publication Types: • Clinical Trial • Clinical Trial, Phase I • Clinical Trial, Phase II • Clinical Trial, Phase III • Clinical Trial, Phase IV • Comparative Study • Controlled Clinical Trial • Corrected and Republished Article • Evaluation Studies • Guideline • Journal Article • Meta-Analysis • Multicenter Study • Practice Guideline • Published Erratum • Randomized Controlled Trial • Review	Structured Process Changes/Workflow Redesign	(((MH "Infusion Pumps") OR AB ("Infusion Pump*" OR "Smart Pump*")) AND ((MH "Medication Errors" OR "Product Recalls and Withdrawals" OR "Workflow") OR (AB "Medication Error*" OR "Workflow" OR "Workflow Redesign" OR "Product Recall*" OR "Product Withdrawal*")))	(((MH "Infusion Pumps") OR (AB "Infusion Pump*" OR "Smart Pump*")) AND ((MH "Medication Errors" OR "Product Recalls and Withdrawals" OR "Workflow") OR (AB "Medication Error*" OR "Workflow" OR "Workflow Redesign" OR "Product Recall*" OR "Product Withdrawal*")))

Method	Search	Search String for: CINAHL	Search String for: MEDLINE
• Scientific Integrity Review • Technical Report • Twin Study • Validation Studies CINAHL Publication Types: • Clinical Trial • Corrected Article • Journal Article • Meta-Analysis • Meta Synthesis • Practice Guidelines • Randomized Controlled Trial • Research Review • Systematic Review			
Search 2008-Present, English Only MedLine Publication Types: • Clinical Trial • Clinical Trial, Phase I • Clinical Trial, Phase II • Clinical Trial, Phase III	Staff Education and Training	(((MH "Infusion Pumps") OR (AB "Infusion Pump*" OR "Smart Pump*" OR "Dose Error Reduction System" OR DERS OR "Intravenous Clinical Integration" OR IVCI OR "Barcode Medication Administration System" OR BMA)) AND ((MH "Medication Errors") OR (AB "Medication Error*" OR "Adverse Event")) AND ((MH "Education") OR AB (Inservice or "In-Service" OR "Staff Education" OR "Staff Training" OR Training OR Education OR Clinician OR Employee OR Staff	(((MH "Infusion Pumps") OR (AB "Infusion Pump*" OR "Smart Pump*" OR "Dose Error Reduction System" OR DERS OR "Intravenous Clinical Integration" OR IVCI OR "Barcode Medication Administration System" OR BMAS)) AND ((MH "Medication Errors") OR (AB "Medication Error*" OR "Adverse Event")) AND ((MH "Education") OR (AB Inservice or "In-Service" OR "Staff Education" OR "Staff Training" OR Training OR Education OR Clinician OR Employee OR Staff

Method	Search	Search String for: CINAHL	Search String for: MEDLINE
• Clinical Trial, Phase IV • Comparative Study • Controlled Clinical Trial • Corrected and Republished Article • Evaluation Studies • Guideline • Journal Article • Meta-Analysis • Multicenter Study • Practice Guideline • Published Erratum • Randomized Controlled Trial • Review • Scientific Integrity Review • Technical Report • Twin Study • Validation Studies CINAHL Publication Types: • Clinical Trial • Corrected Article • Journal Article • Meta-Analysis • Meta Synthesis • Practice Guidelines		OR Physician* OR Doctor* OR Nurse* OR "Nurse Practitioner*" OR "Physical Therapist*" OR "Social Worker*" OR "Physician Assistant*" OR "Occupational Therapist*")))	OR Physician* OR Doctor* OR Nurse* OR "Nurse Practitioner*" OR "Physical Therapist*" OR "Social Worker*" OR "Physician Assistant*" OR "Occupational Therapist*")))

Method	Search	Search String for: CINAHL	Search String for: MEDLINE
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AHRQ Pub. No. 20-0029-EF
March 2020