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Nurses' Acceptance of Smart IV Pump Technology

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Abstract

Background—"Smart" intravenous infusion pumps (Smart IV pumps) are increasingly being implemented in hospitals to reduce medication administration errors.

Objectives—This study examines nurses' experience with the implementation and use of a Smart IV pump in an academic hospital.

Method—Data were collected in three longitudinal surveys: (a) a pre-implementation survey, (b) a 6-week-post-implementation survey, and (c) a 1-year-post-implementation survey. We examined: (a) the technology implementation process, (b) technical performance of the pump, (c) usability of the pump, and (d) user acceptance of the pump.

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Author Contributions

- a. the conception and design of the study
- b. acquisition of data
- c. analysis and interpretation of data
- d. drafting the article or revising it critically for important intellectual content
- e. final approval of the version to be submitted.

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Results—Initially, nurses had a somewhat positive acceptance of the Smart IV pump technology that significantly increased one year after implementation. User experiences associated with the pump in general improved over time, especially perceptions of pump efficiency. However, user experience with the pump implementation process and pump technical performance did not consistently improve from the pre-implementation survey to the post-implementation survey. Several characteristics of pump technical performance and usability influenced user acceptance at the one-year post-implementation survey.

Discussion—These data may be useful for other institutions to guide implementation and post-implementation follow-up of IV pump use; other institutions could use the survey instrument from this study to evaluate nurses' perceptions of the technology. Our study identified several characteristics of the implementation process that other institutions may need to pay attention to (e.g., sharing information about the implementation process with nurses).

Keywords

infusion pump; acceptance process; safety management; Smart IV pump technology; user acceptance; nurses; survey

1. Introduction

“Smart” intravenous infusion pumps (Smart IV pumps) have increasingly been implemented in hospitals in order to reduce medication administration errors (Institute for Safe Medication Practices, 2002; Taxis, 2005; Bates, Vanderveen, Seger, Yamaga, & Rothschild, 2005) even though the evidence for improvement in medication safety is lacking (Nuckols et al., 2008; Rothschild et al., 2005). The Smart IV pump is a relatively new computerized medication delivery technology. Surveys done by the American Society of Health-System Pharmacists show Smart IV pump implementation rates have increased from 32% of hospitals in 2005 to 59% in 2008 (Pedersen, Schneider, & Scheckelhoff, 2006 & 2009). The pump programming software requires end users to perform a set of sophisticated interactive tasks. Smart IV pumps function like general purpose infusion pumps with the added feature of a built-in dose error reduction system designed to “double check” the programmed dose of medication and identify potential programming errors before reaching the patient (ECRI, 2002). The pumps have predetermined drug libraries (or profiles) that specify minimum and maximum dose limits for a given medication. Each pump can have multiple profiles to allow for different dosing limits based on patient population (adult or pediatric) or care setting (e.g., intensive care unit, operating room). The safety features rely upon a user choosing the correct medication and concentration from the correct drug profile. When the programmed dose is outside the predetermined limits, the pump sends an audio and visual ‘alert’ to the user indicating this fact. The user can usually override the alert and proceed with the programmed dose, or reprogram the dose or cancel the infusion programming and start over. Users can also choose a ‘channel label’ from a predetermined pick list for a medication that is not in the drug library to allow users to quickly view the current solution/drug on the pump channel. The major changes required by a nurse when programming a smart IV pump versus a non-smart IV pump include: selecting a drug library appropriate to the care environment, selecting the drug and drug concentration to be administered from the drug library, and responding to alerts from the pump when the programming is outside the limits of the drug library or that the same drug is infusing.

The implementation of the Smart IV pump technology can change users' work flow, requires additional learning, and may increase cognitive workload compared to the use of a traditional intravenous infusion pump (Carayon et al., 2005; Wetterneck, Schroeder, Skibinski, Roberts, & Carayon, 2004). For example, if the pump is used for infusions and the software with the drug limits is not used, the safety benefits of the pump are not realized. There may, however,

be issues with use of the pump safety features (Rothschild et al., 2005; Birk, 2008; Nemeth et al., 2009). To substantially improve patient safety, not only the pump technology but also human behavior and performance involved in the use of the IV pump must be carefully evaluated (Rothschild et al., 2005; Nunnally, Nemeth, Brunetti, & Cook, 2004; Zhang, Patel, Johnson, Chung, & Turley, 2005). User perceptions and acceptance of IV pump technology are therefore important because they can influence the technology's effective use and any potential improvement in patient safety.

2. Background

The nursing informatics and medical informatics literature has long emphasized the importance of human and organizational aspects of information technology (Lorenzi, Riley, Blyth, Southon, & Dixon, 1997; Kaplan, 1997; Staggers & Kobus, 2000; Ammenwerth, Mansmann, Iller, & Eichstadter, 2003; Brennan, 2002; Kaplan, Brennan, Dowling, Friedman & Peel, 2001). The concept of nursing technology acceptance has been studied in relation to a computerized order technology (Staggers & Kobus, 2000), computer-based nursing documentation (Ammenwerth et al., 2003), and recently, electronic medication administration record (Staggers, Kobus, & Brown, 2007). User acceptance of technology is strongly influenced by how users perceive the technical performance and usability of the technology (Staggers et al., 2007; Davis, 1989; Nielsen, 1993). Technical performance includes factors such as system reliability, speed, and accuracy. Usability consists of five attributes: learnability, efficiency, memorability, errors, and satisfaction (Nielsen, 1993). Nunnally et al. (2004) found that complexity and usability problems with pump software impede reliable pump operation by even the most skilled users. User acceptance of technology influences use of the technology (Davis, 1993); therefore understanding factors that influence user acceptance can hopefully lead to consistent use of the technology when implemented.

User training, user involvement, and organizational support throughout the system design and implementation process can also influence user acceptance (Timmons, 2003; Handy, Hunter, & Whitddett, 2001; Mahmood, Burn, Gemoets, & Jacquez, 2000; Karsh, 2004). Lack of training and support can become barriers to user acceptance (Short, Frischer, & Bashford, 2004). On the other hand, user involvement can result in positive attitudes toward the technology (Darr, Harrison, Shakked, & Shalom, 2003; Carayon & Karsh, 2000).

In addition, the effect of demographic variables on user acceptance of health care technology has been addressed in prior studies (Ammenwerth et al., 2003; Dillon, McDowell, Salimian, & Conklin, 1998). These variables include age, level of education, previous use of technology or computers, job skills, work experience, and type of employment. For example, a study found that nurses who reported previous computer use had a more positive attitude toward technology than those who had no prior computer experience (Scarpa, Smeltzer, & Jasion, 1992).

We conducted a repeated cross-sectional survey study to examine nurse perceptions of: (a) the technology implementation process, (b) technical performance of the Smart IV pump, (c) usability of the Smart IV pump, and (d) user acceptance of the Smart IV pump technology. We also examined the predictors of user acceptance of the Smart IV pump technology one year after implementation.

3. Methods

3.1 Study Design and Procedure

The study protocol was approved by the Health Sciences Institutional Review Board of the University of Wisconsin-Madison. Similar to other studies of acceptance of technology (Ammenwerth et al., 2003; Staggers et al., 2007), nurses from a single healthcare organization

were surveyed. Three surveys were completed: a pre-implementation survey and two post-implementation surveys conducted 6 weeks and one year after the implementation. This design is very similar to a study of nursing acceptance of computer-based documentation (Ammenwerth et al., 2003). Ammenwerth et al. (2003) surveyed a group of nurses in four units of a single hospital 3 months before, 3 months after and 9 months after the introduction of the computerized documentation system. This type of survey design can capture both short and long-term effects of the technology on user acceptance.

The pre-implementation survey was paper-based and administered to approximately 600 nurses involved in training sessions on the Smart IV pump use that occurred the week before pump implementation. Some of the nurses were not able to attend pre-implementation training; therefore, our sample did not include all nurse users. Training consisted of hands-on skills training provided by nurse super users with a basic skills checklist and an optional computer-based training module. Pump use instructions were also initially attached to the pumps when sent for use.

The two post-implementation surveys were administered six weeks and then one year after implementation. Both surveys were distributed via email, and reached a larger number of nurses as compared to the pre-implementation survey. The email addresses of nurses were obtained through the hospital's Human Resources Department. The email explained the study objectives, provided a link to access the web-based survey, and stated confidentiality. It was sent to about 1,034 individual nurses' email addresses at six weeks and 1,054 nurses at one year, followed by three email reminders sent to the non-respondents on a weekly basis. These samples included the 600 nurses who were asked to participate in the pre-implementation survey.

3.2 Sample

The survey sample included nurses who worked at an academic hospital that has a Level One trauma center. Nurses were invited to participate in three surveys: a pre-implementation survey (n=190, response rate: 32%), a 6-week-post-implementation survey (n=322, response rate: 31%), and a 1-year-post-implementation survey (n=399, response rate: 38%). Demographic information is provided in Table 1. Chi-square analyses showed that the nurses participating in the three surveys have similar demographic characteristics. We also compared the survey participants to the target group, i.e. the entire nursing staff of the hospital, on several demographic variables (age, gender and hospital unit), and did not find any differences.

3.3 Surveys

In all three surveys, the questions on expected/perceived technology characteristics were adapted from the Questionnaire for User Interface Satisfaction version 5.0, with a focus on usability and system capabilities (Chin, Diehl, & Norman, 1998). The question on user acceptance of the pump technology was adapted from Bailey and Pearson (1983): "Please circle the number that best reflects your acceptance of the smart IV pump technology." A score of 10 indicated "like it very much and eager to use," while a score of 1 indicated "dislike it very much and don't want to use." Demographic data were collected in all three surveys, including age, education, experience with the present employer, experience in the present job position, and the nursing unit on which they primarily worked.

The following questions were included in both the pre-implementation survey and the 6-week-post-implementation survey:

- Twelve questions on pump implementation: 5 questions on information received about pump implementation, 6 questions on user inputs in decision making regarding pump implementation, and 1 question on supplemental training materials.

- Three questions on expected/perceived technical performance of the pump.
- Eighteen questions on expected/perceived usability of the pump: 3 questions on learnability, 1 question on memorability, 8 questions on efficiency, 3 questions on errors, and 3 questions on satisfaction.

In the one-year-post-implementation survey, the questions on pump implementation were excluded except for the one question on supplemental training materials. We added three newly constructed questions on pump technical performance based on feedback captured from users through structured (written) and unstructured (verbal) information-gathering mechanisms post-implementation. The new questions were pilot tested with nurses for face validity. Likewise we conducted structured usability evaluations post-implementation which led us to also add eight questions on usability (2 questions on learnability, 2 questions on efficiency, 2 questions on errors and 2 questions on satisfaction), some of which were taken from Keohane et al (2005).

3.4 Data analysis

Data were analyzed with SPSS© 14.0. For each of 6 groups of variables (implementation, technical performance, learnability-memorability, efficiency, errors, and satisfaction), we first performed a multivariate ANOVA to find out whether there were differences between the 3 rounds. If the MANOVA was found to be statistically significant, follow-up ANOVAs were conducted and post-hoc tests (Bonferroni tests to address the issue of multiple comparisons) were performed to compare user perceptions and user acceptance of the Smart IV pump across the three surveys for each individual variable. The Wilk's lambda is used in MANOVA to test the null hypothesis that the populations have identical means.

Stepwise regression analysis was used to examine the predictors of user acceptance at one-year post-implementation. Because of the large number of potential predictors and the risk of multicollinearity, five groups of predictors of user acceptance were examined separately: (a) 6 questions on technical performance of the Smart IV pump, (b) 6 questions on learnability and memorability, (c) 10 questions on efficiency, (d) 5 questions on errors, and (e) 5 questions on satisfaction. As discussed in the background section, several demographic variables can influence user acceptance of technology. Therefore, the first step of the analysis was to perform a regression analysis of user acceptance on the following demographic variables: age, level of education, and experience in current position. This regression led to an adjusted R^2 of 6%: only tenure was a significant predictor of user acceptance (beta coefficient = $-.26$, $p < .001$): nurses with greater experience in their current position tended to report lower levels of acceptance. The second step of the analysis used the residuals from the first regression as the dependent variable and explored the contribution of the five groups of predictors on user acceptance after controlling for the demographic variables.

4. Results

4.1 Perceptions of technology implementation, technical performance and usability

Data on *technology implementation*, *technical performance* of the Smart IV pump, and *usability* of the Smart IV pump are provided in Table 2 to Table 4. The MANOVA's for each of the 6 groups of variables were all found to be statistically significant ($p < .001$) (see Table 2, Table 3 and Table 4 for additional information on the MANOVA's). The results reported in the rest of this section are based on the Bonferroni post-hoc tests.

In the pre-implementation survey and 6-week-post-implementation survey, on average, respondents reported somewhat positive perceptions of *information* received about the Smart IV pump implementation (means varying from 4.96 to 5.52 on 7-point scales); their perceptions

of *user inputs* in decision making on pump implementation were somewhat negative on average (means varying from 3.76 to 4.13 on 7-point scales) (see Table 2). One measure - *usefulness of information received about pump implementation* - was found to be significantly different in the pre- and post-implementation surveys ($p < .05$). Respondents rated the *information* they received more useful before the implementation than six weeks after implementation. In the three surveys, there was a significant difference in user perceptions of *supplemental training materials* ($p < .01$). Respondents reported that the *training materials* were more confusing in the 6-week and 1-year-post-implementation surveys ($p < .01$ for both comparisons) than before implementation.

In the three surveys, respondents reported somewhat positive perceptions of the *technical performance* of the Smart IV pump (means varying from 5.16 to 6.55 on 10-point scales), except for the two measures added in the one-year-post-implementation survey about pump noise (see Table 3). Because nursing staff had verbally complained of “annoying” air-in-line alarms and beeps resulting from a delay on a continual basis from the time of implementation, these two questions were added. User experience with pump *reliability* and *noise* significantly changed from pre- to one-year-post-implementation ($p < .05$ and $p < .001$, respectively). Respondents’ perception of pump *reliability* one year after implementation was significantly lower than before implementation ($p < .05$). Compared to their expectations of pump *noise* before implementation, more negative responses were given in both the 6-week-post-implementation survey and the 1-year-post-implementation survey ($p < .001$ for both comparisons).

Responses to questions on *learnability* of the Smart IV pump were generally somewhat positive (means varying from 5.33 to 6.55 on 10-point scales) (see Table 4). *Learning to operate the pump* became easier one year after implementation, compared to either before or six weeks after implementation ($p < .001$ for both comparisons). Responses to the item “*pump is designed for all levels of users*” were more positive one year after implementation than before or six weeks after implementation ($p < .05$ for both comparisons).

Responses to the questions on *memorability* of the Smart IV pump were somewhat positive (means varying from 5.38 to 5.66 on 10-point scales) (see Table 4). No significant difference was found from pre- to 1-year-post-implementation.

Across the three surveys, responses to the questions on *efficiency* of using the Smart IV pump were mostly somewhat positive (means varying from 3.95 to 5.36 on 7-point scales) (see Table 4). Responses tended to be positive for two questions on *efficiency* related to the pump in general improving patient safety (means varying from 4.87 to 5.36) and for the specific question on the drug libraries increasing safety and quality (mean 5.30), and less positive for the question on *ease of use of the pump in emergency situations* (mean: 4.03) (Note: this question was added in the one-year-post-implementation survey). For seven out of eight questions on *efficiency*, perceptions improved from the six-week post implementation to one-year-post-implementation: “*enables me to accomplish task more quickly*” ($p < .001$), “*improves the quality of care I provide*” ($p < .05$), “*improves the safety of care I provide*” ($p < .01$), “*enhances my effectiveness on the job*” ($p < .01$), “*makes it easier to do my job*” ($p < .001$), “*increases the safety of care provided to our patients*” ($p < .001$), and “*pump functions as I expect*” ($p < .01$). Responses to the question “*task can be performed in a straightforward manner*” did not change over time.

In the three surveys, respondents’ ratings of *alarm* and *alert messages*, and *error recovery* were also somewhat positive (means varying from 5.18 to 6.18 on 10-point scales) (see Table 4). Six weeks after implementation, the respondents reported less positive perceptions of *alarm messages for pump functioning* than they expected before implementation ($p < .01$), which remained less positive in the 1-year-post-implementation surveys. User perceptions of *alert*

messages for the drug library became significantly more positive one year after implementation, compared to six weeks after implementation ($p<.001$).

Respondents' *satisfaction* with the Smart IV pump was addressed by the ratings of their interaction with the pump (see Table 4). Nurses reported easier interaction with the pump one year after implementation, compared to either before or six weeks after implementation ($p<.001$ for both comparisons). They also reported that the pump was more rigid six weeks after implementation than what they expected before implementation ($p<.05$); however, the perceptions returned to pre-implementation levels one year after implementation.

4.2 User Acceptance of Smart IV Pump Technology

Data on *user acceptance* across the three surveys are displayed in Figure 1. *User acceptance* of the Smart IV pump technology was positive (means varying from 6.53 to 7.20 on 10-point scales), and significantly increased one year after implementation as compared to six weeks after implementation ($p<.001$).

4.3 Predictors of user acceptance

Table 5 shows the results of the regression analysis performed to examine the predictors of user acceptance as measured at the one-year post-implementation survey. The five groups of predictors were significantly related to user acceptance (adjusted R^2 from 26% for learnability and memorability to 64% for efficiency). With regard to technical performance, nurses who reported the pump to be reliable, to have sufficient programming speed, to produce useful alert messages for drug library, and to be quiet were more likely to accept the pump. Out of 6 questions on learnability and memorability, only the question on "designed for all levels of users" was a significant predictor of user acceptance. Five of 10 questions on efficiency were significant predictors of user acceptance. Nurses who reported more positive perceptions of the pump's efficiency (e.g., pump making one's job easier to do, pump functioning as expected) were more likely to accept the pump. Four of the five questions on errors and all of the questions on satisfaction were significant predictors of user acceptance. When nurses reported that it was easy to correct mistakes, that using drug libraries helped prevent medication errors, that alarm messages for pump functioning were acceptable, and that the pump was able to identify a problem and provide an appropriate alarm, their level of pump acceptance was higher.

5. Discussion

Many healthcare organizations are adopting new technologies designed to improve quality of care and patient safety. In particular, hospitals and clinics are making significant financial investments to purchase and implement new technologies, such as Smart IV pump and bar coding medication administration technologies, as an effort to reduce medication errors and improve patient safety (Pedersen et al., 2006). Several studies have shown that a large proportion of medication errors can be attributed to human errors; however, technologies are not the panacea to reducing or preventing medication errors (Battles & Keyes, 2002), and can even introduce a new set of errors (Koppel, Metlay, Cohen, et al., 2005). When designing and implementing a technology, it is important to consider the human and organizational factors associated with the technological change (Lorenzi et al., 1997; Smith & Carayon, 1995). Findings from studies of the human and organizational impact of technologies can benefit the manufacturers of these technologies to improve the technologies' design and reduce risks of human error. They can also help healthcare organizations in developing improved strategies for implementing technologies by further understanding the end users' viewpoint.

5.1 Nursing acceptance of Smart IV pump

Our study examined nurses' expectations towards a Smart IV pump before implementation, as well as nurses' perceptions of the pump shortly after implementation (six weeks) and one year after implementation. Such a survey method allowed us to understand the dynamics of user experience regarding the Smart IV pump technology. For instance, learnability of the Smart IV pump improved over time, which indicates a positive trend over time: one year post implementation nurses felt more comfortable with using the Smart IV pump technology. This improvement in perceived learnability may be a reflection of increased pump use and experience.

Nurses tended to report more negative perceptions of the Smart IV pump implementation process (e.g., usefulness of information received about pump implementation and clarity of training materials) six weeks after implementation, compared to what they perceived before implementation. This suggests that the implementation of the Smart IV pump technology in a hospital can be a much more complicated process than planned and expected. After using the Smart IV pump technology for 6 weeks, nurses felt that the implementation process was more negative, suggesting that more attention should have been devoted to this process, in particular regarding information about the pump implementation and the training materials. Lorenzi and Riley (2003) have highlighted the need for further consideration of the change process when implementing a new technology in a healthcare organization. Our study highlights the need for better communication with the end users (e.g., information about the implementation timeline), as well as the need for high quality training materials that end users can refer to when needed.

Several technical performance issues of the Smart IV pump temporarily worsened over time: nurses' perceptions of speed, reliability, and noise became more negative from the pre-implementation survey to the 6-week post-implementation survey, but speed nearly returned to the pre-implementation level one year after implementation. Nurses' perceptions of pump reliability and noise, however, did not improve after one year, despite the fact that nurses had been using the Smart IV pump for a significant amount of time. Other technical performance features, such as alarms, were only assessed in the one-year post-implementation because of feedback collected by a nurse pump coordinator through formal and informal reporting mechanisms. It is unlikely that these perceptions of technical performance factors (e.g., reliability, noise, and alarms) will improve over time (beyond the one-year post implementation period), unless the manufacturer redesigns the technology to address these technical performance issues. Continuous interaction between the users and the manufacturer beyond the initial implementation period can provide useful information about redesigning components of the technology to improve its usability, use and, therefore, acceptance. Data on end-user perceptions are an important input into this discussion. Our team employed a mixed methods approach to the evaluation of the implementation of the Smart IV pump and user perceptions of the device. This approach allowed us to collect and triangulate data from multiple sources, e.g. proactive risk assessment (Wetterneck et al. 2006), observations (Carayon et al. 2005), focus groups, usability testing (Hundt et al. 2005), and an end-user issues list. As such we could adjust our evaluation techniques over time to evaluate new issues (Hundt, et al. 2005), and share data with the organization and the vendor. We also used the data to make changes to new user training and ongoing training on the IV pump, processes for dealing with pump alerts and alarms, and for recommending best practices when using the pumps in emergency situations.

Nurses' perceptions of usability (e.g., learnability, efficiency, error recovery, and satisfaction) tended to improve one year after implementation. However, we did not find a significant change in memorability from pre-implementation to one-year post-implementation. After using the Smart IV pump for about one year, nurses' ratings of the item "remembering names and use

of commands (difficult-easy)” remained unchanged. This result points to a potentially severe usability problem that should be further examined. Hospitals may need to create materials for users that list important features of the pump as well as outline the hospital-specific drug libraries and channel labels available and ensure that these materials remain present long after pump implementation. Other usability characteristics also deserve further attention. For instance, overall, the perception of ease of use of the pump in emergency situations was much less positive than other efficiency-related pump characteristics. Keohane et al. (2005) found that 51% of nurses in a cardiothoracic surgical unit reported ease of use of the same Smart IV pump in emergency situations; larger numbers of nurses reported positive perceptions of other features of the Smart IV pump technology (e.g., ease of programming). Both groups of nurses had positive perceptions that the pump increased quality and safety (75% responded 5 or higher on the 7 point scale vs 69% in Keohane et al. (2005)) and that the pump prevented medication errors (73% responded 5 or higher on the 7 point scale vs. 59% in Keohane et al. (2005)). Some of these usability issues may be difficult to identify unless the technology is used in a real ‘production’ environment. Therefore, interaction between the users and the manufacturer needs to continue beyond the initial phase of implementation.

Overall, nurses’ acceptance of the Smart IV pump technology was positive, and improved over time: acceptance significantly increased one year after implementation as compared to six weeks after implementation. A recent series of focus groups with nurses who had been using Smart IV pump technology for at least one year also found positive nurses’ perceptions about the technology (McAlearney et al., 2007). Our survey results coincide with many of the perceived improvements reported by nurses, e.g., improved learnability and efficiency. After one year of pump use by nurses, acceptance of the pump was significantly influenced by the technical performance of the pump, in particular reliability and programming speed, as well as several usability characteristics, in particular perceived efficiency, error recovery, use of drug libraries, acceptable and appropriate alarm messages, and satisfaction with the pump interface. In order to maintain and continuously improve nurses’ acceptance of pump technology, the technical performance and usability characteristics of the pump need to be monitored and improved if necessary.

5.2 Design and implementation of Smart IV pump technology

Although use of infusion pumps for intravenous medication administration is now commonplace and essentially mandatory, the use of the special pump safety features, e.g., the built-in dose error reduction system, is not mandatory. In fact, users can continue to use the dose-rate calculator in the pumps or hand calculate the infusion settings and proceed with administration, thereby bypassing the protection inherent to the drug library and dose double check. Rothschild et al. (2005) conducted a study on the impact of smart IV pumps and found that in 25% of drug orders, the nurses bypassed the library either intentionally or accidentally. McAlearney et al. (2007) identified several strategies used by nurses in order to facilitate (or allow) their use of the Smart IV pump in a busy clinical environment; some of those strategies defeated the safety features of the technology. For instance, nurses would program the pump manually and not use the programming capability of the pump. The usability of the pumps can affect the user’s decision to use the safety features (i.e. acceptance), thus making learning, memorability, and efficiency very important. There may also be technical performance tradeoffs for the nurse to use these safety features such as increased time to program and more alerts or alarms (that are noisy and slow down the user) (McAlearney et al., 2007). Minimizing the less desirable features, such as decreased speed of programming and noisy alarms, through training and software redesign and accentuating the safety features of the pump during implementation may make the safety features the ‘easy and accepted’ way to program the pump.

5.3 Strengths and limitations of the study

The study involved the collection of survey data from nurses in a single academic hospital; therefore, we cannot generalize our results to other hospitals. However, our results have many similarities with the few studies of Smart IV pump implementation and use in hospitals (Rothschild et al., 2005; McAlearney et al., 2007).

This is the first time that many of these questions have been used for research on Smart IV pumps; therefore, there are no established norms for the question responses and the reliability of the questions was not reanalyzed after adapting them for the survey. However, these data begin to give a baseline for usability and technical performance questions to study the implementation of Smart IV pumps and for institutions and the health care community to learn how to better implement technologies in health care to achieve the maximum use and therefore the maximum patient safety benefits. It also provides data to share with vendors of technology to guide the redesign of software and hardware to meet the needs of the user. The survey response rate, although lower than desired, still provided the researchers with sufficient data from which to judge the user perceptions of the pump. The response rate is, however, typical of health care setting surveys.

Because two different modes of survey administration (paper survey for the pre-implementation survey, and web survey for the two post-implementation surveys) were used, it is difficult to assign the over-time changes in perceptions of technology acceptance and its contributors to true changes. Many of the changes that were captured in the surveys were explained either in light of learning effects or changes that occurred post-implementation; however, these explanations should be considered as tentative.

5.4 Future Research Considerations

We used surveys to understand collective end-user perceptions of the usability of the IV pump, the implementation process, and their overall acceptance of the pump. By understanding these perceptions, we hope to better understand the factors that ultimately effect use of the pump and its safety software. Similar research could explore perceptions of other commercially available smart IV pumps to inform health care organizations when choosing an IV pump. Further research should also be done to understand usability on an individual level through, for example, think aloud usability protocols or observation in-situ, to further define explicit hardware and software needs and changes that would improve use. Also, we evaluated acceptance and usability of the pump while others have evaluated safety outcomes after smart IV pumps are implemented (Rothschild et al 2005; Nuckols et al 2008). How acceptance and usability perceptions influence actual pump use and how actual pump use influences safety outcomes are yet to be explored.

6. Conclusion

Our study demonstrated positive user acceptance of Smart IV pump technology by nurses. User experience with the pump in general improved over time. However, user experience of the pump implementation process and pump technical performance did not improve from pre-implementation to post-implementation. The main problems with the Smart IV pump technology reported by nurses included air-in-line alarms, and beeps resulting from a delay, issues that will require technology solutions from the vendor. Several characteristics of the technical performance and usability of the pump predicted user acceptance, therefore indicating the need for continuous attention to those characteristics, in particular in case the manufacturer redesigns the pump. Data from end-user surveys can be shared with vendors to stimulate improvements in the hardware and software to improve use and surveys can be used to gauge end-user perceptions with pump changes. Increased collaboration between the designers and

manufacturers of the technologies and the user community can lead to many benefits; part of this collaboration should rely on understanding the use of the technologies in a real 'production' environment.

Summary table:

What was already known on the topic

- Smart infusion pumps have the potential to prevent medication errors
- Perceived user acceptance of technology and usability influence actual use of technology

What this study added to our knowledge of the study

- Nurse acceptance of a new smart infusion pump was positive and improved over time after implementation

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Figure 1. User Acceptance of Smart IV Pump Technology

"Please circle the number that best reflects your acceptance of the Smart IV pump technology:"

Table 1

Demographic Information on Survey Participants

		Pre- implementation N=190 (%)	6-week-post- implementation N=322 (%)	1-year-post- implementation N=399 (%)
Age	1. 34 or less	42	43	45
	2. 35–44	27	30	26
	3. 45–54	24	21	21
	4. 55+	7	6	8
Education	1. Associate or bachelor's degree in nursing	88	86	86
	2. Some graduate school or graduate degree	12	14	14
Experience with present employer	1. less than 1 year	19	16	14
	2. 1 to 5 years	45	44	42
	3. 6 to 15 years	18	25	28
	4. more than 16 years	18	15	16
Experience with current job position	1. less than 1 year	20	19	19
	2. 1 to 5 years	52	46	49
	3. 6 to 15 years	19	24	21
	4. more than 16 years	9	11	11

Table II

User Expectations and Perceptions of Smart IV Pump Technology Implementation

		Pre- implementation N=190 Mean (SD)	6-week-post- implementation N=322 Mean (SD)	1-year-post- implementation N=399 Mean (SD)
Information received about pump implementation	<ul style="list-style-type: none"> Insufficient (1) - sufficient (7) Incomplete (1) – complete (7) Non-timely (1) - timely (7) Vague (1) – precise (7) Useless (1) – useful (7) * 	5.22 (1.52)	5.04 (1.47)	N/A
User inputs in decision-making on pump implementation	<ul style="list-style-type: none"> Non-timely (1) – timely (7) Insufficient (1) - sufficient (7) Useless (1) – useful (7) Meaningless (1) – meaningful (7) Bad/poor (1) – good (7) Nonproductive (1) – productive (7) 	3.98 (1.95)	3.83 (1.81)	N/A
		3.82 (1.94)	3.76 (1.83)	N/A
		4.03 (2.00)	3.82 (1.86)	N/A
		4.04 (2.00)	3.78 (1.86)	N/A
		4.12 (1.99)	3.81 (1.85)	N/A
		4.13 (1.94)	3.82 (1.84)	N/A
Supplemental Training materials	<ul style="list-style-type: none"> Confusing (0) – clear (9) ** 	5.68 (2.00)	4.99 (2.28)	5.11 (2.01)

Wilk's lambda=0.035 (p<.001); Bonferroni post-hoc tests:

* p<.05,

** p<.01

Underlined items achieved statistical significance for the test of change over time.

Note: The numbers in parentheses indicate the scores assigned to end-points for each question.

Table III

Perceived Technical Performance of the Smart IV Pump

		Pre- implementation N=190 Mean (SD)	6-week-post- implementation N=322 Mean (SD)	1-year-post- implementation N=399 Mean (SD)
Technical performance	• Programming speed: too slow (0) - fast enough (9)	5.46 (2.07)	5.26 (2.48)	5.53 (2.34)
	• <u>Reliability: unreliable (0) – reliable (9)</u> *	<u>6.55 (1.60)</u>	6.33 (2.04)	<u>6.08 (2.11)</u>
	• <u>Noise: noisy (0) – quiet (9)</u> ***	<u>6.39 (1.71)</u>	5.18 (2.66)	<u>5.16 (2.61)</u>
	• Alert messages for drug library: useless (0) – useful (9)	N/A	N/A	6.21 (2.05)
	• Air-in-line alarms: annoying (0) – useful (9)	N/A	N/A	3.42 (3.29)
	• Beeps resulting from a delay: annoying (0) – useful (9)	N/A	N/A	3.37 (3.21)

Wilk's lambda=0.087 (p<.001); Bonferroni post-hoc tests:

*
p<.05,

p<.001

Underlined items achieved statistical significance for the test of change over time.

Note: The numbers in parentheses indicate the scores assigned to end-points for each question.

Table IV

Perceived Usability of the Smart IV Pump

	Pre-implementation N=190 Mean (SD)	6-week-post-implementation N=322 Mean (SD)	1-year-post-implementation N=399 Mean (SD)
Learnability			
• Learning to operate pump: *** difficult (0) – easy (9)	5.46 (2.12)	5.84 (2.33)	6.55 (2.11)
• Exploring new features by trial and error: difficult (0) – easy (9)	5.74 (1.98)	5.59 (2.25)	5.95 (2.27)
• Designed for all levels of users: never (0)–always (9) **	5.33 (1.98)	5.35 (2.03)	5.77 (1.93)
• Knowing available channel labels: difficult (0) – easy (9)	N/A	N/A	6.07 (2.31)
• Pump software navigation: difficult (0) – easy (9)	N/A	N/A	5.74 (2.16)
Memorability			
• Remembering names and use of commands: difficult (0) – easy (9)	5.38 (2.04)	5.50 (2.22)	5.66 (2.33)
Efficiency			
• Accomplishes tasks more quickly: strongly disagree (1) - strongly agree (7) ***	4.18 (1.52)	4.19 (1.62)	4.70 (1.54)
• Improves quality of care: strongly disagree (1) - strong agree (7) *	4.67 (1.59)	4.61 (1.55)	4.97 (1.51)
• Improves safety of care: strongly disagree (1) - strongly agree (7) **	5.12 (1.54)	4.97 (1.46)	5.36 (1.55)
• Enhances effectiveness on job: strongly disagree (1) - strongly agree (7) ***	4.56 (1.58)	4.45 (1.56)	4.87 (1.52)
• Makes it easier to do job: strongly disagree (1) - strongly agree (7) ***	4.20 (1.66)	4.17 91.66)	4.77 (1.68)
• Increases safety of care provided to patients: strongly disagree (1) - strongly agree (7) ***	5.03 (1.53)	4.87 (1.49)	5.32 (1.55)

	Pre-implementation N=190 Mean (SD)	6-week-post-implementation N=322 Mean (SD)	1-year-post-implementation N=399 Mean (SD)
<ul style="list-style-type: none"> Tasks can be performed in a straightforward manner; never (0) - always (9) Smart IV pump will function as I expect; never (0) - always (9) *** Easy to use pump in emergency situations; strongly disagree (1) - strongly agree (7) Drug libraries increase safety and quality of care; strongly disagree (1) - strongly agree (7) 	5.49 (1.96)	5.53 (2.10)	5.75 (2.10)
	6.17 (1.68)	5.60 (1.99)	6.05 (1.84)
	N/A	N/A	4.03 (1.77)
	N/A	N/A	5.30 (1.59)
Errors	5.93 (2.00)	5.18 (2.70)	5.47 (2.67)
<ul style="list-style-type: none"> Alarm messages for pump functioning: frustrating (0) – acceptable (9) ** Alert messages for drug library: frustrating (0) – acceptable (9) *** Correcting your mistakes: difficult (0) – easy (9) Using drug libraries helps prevent medication errors: strongly disagree (1) - strongly agree (7) Pump is able to identify a problem and give an appropriate alarm: strongly disagree (1) - strongly agree (7) 	5.80 (2.17)	5.58 (2.27)	6.18 (2.07)
	5.53 (2.03)	5.37 (2.29)	5.74 (2.10)
	N/A	N/A	5.22 (1.62)
	N/A	N/A	4.94 (1.55)
Satisfaction	5.56 (2.01)	5.76 (2.18)	6.43 (2.05)
<ul style="list-style-type: none"> difficult (0) – easy (9) *** frustrating (0) – satisfying (9) rigid (0) – flexible (9) ** Your level of confidence in responding to alert messages: not at all confident (0) - very confident (9) 	5.34 (2.14)	5.24 (2.31)	5.63 (2.50)
	5.88 (1.99)	5.34 (2.20)	5.78 (2.18)
	N/A	N/A	6.69 (1.91)

	Pre- implementation N=190 Mean (SD)	6-week-post- implementation N=322 Mean (SD)	1-year-post- implementation N=399 Mean (SD)
• I trust pump working correctly; strongly disagree (1) - strongly agree (7)	N/A	N/A	5.03 (1.49)

MANOVAs: learnability-memorability: Wilk's lambda=0.099, efficiency: Wilk's lambda=0.032, errors: Wilk's lambda=0.103, and satisfaction: Wilk's lambda=0.107 (all significant at p<.001).

Bonferroni post-hoc tests:

* p<.05,
** p<.01,
*** p<.001

Underlined items achieved statistical significance for the test of change over time.

Note: The numbers in parentheses indicate the scores assigned to end-points for each question.

Table V
Predictors of User Acceptance – Results of Stepwise Regression Analysis (one-year post-implementation survey)

	Technical performance	Learnability and memorability	Efficiency	Errors	Satisfaction
Total # of variables	6	6	10	5	5
Adjusted R²	51%	26%	64%	47%	61%
Significant predictors (beta-coefficient)	<ul style="list-style-type: none"> Reliability (.35^{***}) Speed (.32^{***}) Useful alert messages for drug library (.14^{**}) Noise (.09[*]) 	<ul style="list-style-type: none"> Designed for all levels of users (.52^{***}) 	<ul style="list-style-type: none"> Makes it easier to do job (.22^{***}) Function as I expect (.29^{***}) Improves safety of care (.17^{***}) Tasks can be performed in a straightforward manner (.11[*]) Enhances effectiveness (.15[*]) 	<ul style="list-style-type: none"> Easy to correct mistakes (.30^{***}) Using drug libraries helps prevent medication errors (.21^{***}) Acceptable alarm messages for pump functioning (.26^{***}) Pump is able to identify a problem and give appropriate alarm (.19^{***}) 	<ul style="list-style-type: none"> Satisfying pump interface (.35^{***}) I trust pump working correctly (.20^{***}) Easy pump interface (.14[*]) Flexible pump interface (.15[*]) Confident in responding to alert messages (.09[*])

* p<.05,

** p<.01,

*** p<.001