RESEARCH ARTICLE

A qualitative analysis of intravenous smart pump usability

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Abstract

Aim: To understand the experience of critical care nurses when performing common, yet error-prone, programming tasks on two unfamiliar intravenous smart pumps.

Design: A qualitative descriptive study using data collected during a previous quantitative pilot study.

Methods: Following completion of common intravenous programming tasks each participant was interviewed using a semi-structured interview guide. All interview data were coded line-by-line and thematic analysis revealed themes across all participants' interviews.

Results: The following four themes were identified: appreciation for attractive design features, the need for efficiency, the importance of intuitive use and concern for patient outcomes. Overall, these themes provide evidence that nurses strongly prefer a more usable intravenous smart pump interface that integrates safeguards to efficiently improve patient outcomes. Findings support the need for intravenous smart pump technology to be developed with an intuitive interface that decreases the level of cognitive demand and will lead to improved patient safety.

KEYWORDS
critical care nursing, infusion pumps, intravenous administration, intravenous infusions, user-centered design

1 | INTRODUCTION

Intravenous (IV) smart pumps (IVSP) are one of the most widely used healthcare technologies in the United States acute care, with about 90% of hospitalized patients receiving at least one medication via IVSP (Ding et al., 2015; Fan et al., 2014; Giuliano, 2018a, 2018b; Kuitunen et al., 2020). Dose error reduction systems (DERS) were introduced in the late 1990s and were quickly adopted as a standard for improving infusion safety and reducing medication errors (Giuliano & Ruppel, 2017). According to the Institute for Safe Medication Practices, 99% of US hospitals currently use IVSP (Institute for Safe Medication Practices, 2020). IVSP use built-in drug libraries which are customizable by the hospital pharmacy. The drug library provides the user with a list of medications from which to choose, while the DERS provides alerts if programming is outside set dosing limits (Giuliano & Ruppel, 2017). Despite wide adoption of IVSP equipped with DERS and drug libraries, their use has not eliminated IV medication error and data support that IVSP use has not had any significant impact on decreasing the rate of adverse drug events (ADEs; Giuliano, 2018a; Ohashi et al., 2014; Schnock et al., 2016, 2018). Since IVSP introduction, innovation of clinical features and usability has been fairly stagnant with the most commonly used IVSP models using outdated design and technology (Giuliano & Ruppel, 2017). This study aims to understand the experience of critical care nurses when performing common, yet error-prone, programming tasks on two unfamiliar IVSP. By exploring user experience, valuable insight can be gained to inform future IVSP innovation designed to improve usability and decrease risk to patients.

2 | BACKGROUND

Adverse events associated with the use of IVSP are among the most frequent sources of error reported to the US Food and Drug Administration as compared with other medical technology devices (Institute for Safe Medication Practices, 2020; Snijder et al., 2015). When an error occurs involving IV medications, it is often difficult to detect (Cassano-Piché et al., 2012) and poses significant risk to the patient due to the drugs' commonly low therapeutic thresholds and rapid onsets (Ding et al., 2015; Fahimi et al., 2015). The majority of ADEs involving medications delivered via IV infusion are a result of programming errors (NQF, 2012).

The programming of IVSP requires a high level of cognitive demand because IVSP involve many steps and significant human–device interaction (Campoe & Giuliano, 2017; Giuliano, 2018a). Higher cognitive demands are consequential because they compromise a nurse's ability to provide safe patient care (Cassano-Piché et al., 2012; Jennings, 2021). Risk of error is exacerbated in the ICU, where nurses experience high cognitive demands related to the large volume of required patient care tasks, high medical acuity and frequent interruptions from families, other staff and medical alarms (Cassano-Piché et al., 2012). In this environment, reliance on IVSP is especially high, with patients receiving an average of seven IV medications per day (Moss et al., 2008). IVSP-related medication errors often occur when a complex device interface leads to use errors or bypassing of safety features such as the DERS and the drug library (Giuliano, 2018a; Giuliano & Ruppel, 2017). When clinicians are tasked with the care of patients in busy clinical environments, they report feeling rushed during IVSP programming due to competing work demands, patient acuity and time constraints (Giuliano & Ruppel, 2017). For example, 78% of all errors occurring in the ICU are medication errors, many of which are IV medications (Di Muzio et al., 2017); furthermore, only 56% of infusions have been found to be delivered in the time frame prescribed (Monroy Aceves et al., 2013). Therefore, technology that lowers IV administration complexity may have promising implications for reducing medical errors in critical care environments.

If we are to improve IVSP usability and safety, it is important to consider error as primarily the result of system failures rather than individual human errors (Giuliano, 2018a; NQF, 2012). Understanding nurses' experiences and preferences for IVSP programming is a critical step towards developing safer technology.

2.1 | Research question

What is the critical care nurse experience when performing common, yet error-prone, programming tasks on two unfamiliar IVSP?

3 | DESIGN

This study follows qualitative descriptive design to evaluate critical care nurse experiences using unfamiliar IVSP models. Interview transcripts were collected at the same time as a quantitative pilot study which was conducted to determine programming complexity and time required to complete tasks. This analysis of the qualitative data has been conducted independent of quantitative analysis which is published separately.

4 | THEORETICAL FRAMEWORK

This study is guided by Vincent et al.'s (1998) framework that applied a 'human factors' approach to the clinical context. A 'human factors' approach recognizes the complex roles of organizational, socio-technical and human factors in causing adverse events (Vincent et al., 1998). In a healthcare setting, these factors include the institutional context, organizational factors, the work environment, team and staff factors, task factors and patient characteristics (Vincent et al., 1998). This theoretical perspective supports our study's core assumption that understanding equipment design, nursing practice and nursing preferences is critical to prevent medical errors. The clinical environment presents many opportunities for error when devices that are intended to improve safety are overly complex and not user-friendly. Human factors principles require that systems be designed for usability within their intended environments. Achieving the aims of this study will improve the understanding of current usability of IVSP for experienced nurses, thereby contributing to the body of knowledge which will improve patient safety through innovative IVSP design. When this user experience is combined innovation, human factors principles are accounted for within the complex clinical roles for device use by clinicians.

5 | METHODS

5.1 | Sample

Participants included a convenience sample of critical care nurses (n = 15) from Boston-area hospitals who worked a minimum of 20 hr per week in an intensive care setting. These nurses were recruited using a recruiting agency. Nurses included in the study had at least 2 years of experience as a critical care nurse and at least 2 years of experience working with and programming large-volume IVSP (e.g. Alaris, ICU Medical, B. Braun, Sigma/Baxter etc.).

5.2 | Data collection

Three IVSP were included in this study, one prototype designed with usability features in mind and two currently on the market. However, each participant was only asked to use two of the IVSP available, the prototype and one of the current IVSP models that they did not have prior experience using. Face-to-face semi-structured interviews were conducted after participants had performed five IV medication tasks on the two assigned IVSP.

Qualitative data collection was completed by the research assistant using the interview guide developed for the study (Table 1). All interviews were audio–video recorded. Quantitative results describing variations in programming time and error occurrence during these five tasks has been previously published (Giuliano, 2015). Interviews were videotaped and digitally recorded followed by verbatim transcription. The average duration of both the quantitative and qualitative data collection was 1.5–2 hr and each participant received an honorarium of $175 to cover their time and efforts onsite and any associated travel expenses. Despite this honorarium, it is believed that this does not introduce any positive bias because there was no association between the honorarium and any IVSP manufacturer or other stakeholder.

5.3 | Analysis

Once all data collection was completed, interviews were professionally transcribed. Data were analysed using line-by-line in vivo coding individually by the first two authors. Both authors performed reflexivity through frequent memoing to actively assess their own perspectives and potential biases. Peer debriefing was performed between both authors, the second author was not a subject matter expert and was able to ensure a balanced perspective during thematic analysis. The two authors met to discuss codes, address coding questions and thoroughly discuss points of disagreement. Constant comparison was used to identify resultant patterns and categories (Marshall & Rossman, 2016). Constant comparison is a data analysis method in which researchers compare data to existing codes, group similar data into categories and develop themes and concepts (Streubert & Carpenter, 2011).

After analysis of 12 participants, no new codes were identified through analysis of the remaining three participant transcripts, indicating data saturation had been achieved (Marshall & Rossman, 2016). Once data saturation occurs, it is crucial for researchers to continue to identify alternative but plausible explanations; this step ensures the resultant patterns, categories and overarching themes finally present an accurate depiction and assertion of the data analysed (Marshall & Rossman, 2016). Therefore, the entire sample of 15 participants was analysed. An audit trail was generated to demonstrate dependability. Table 2 describes codes and resultant categories.

Through a process known as abstraction, organizing and reorganizing codes into contextual categories provided the basis for thematic development (Lindgren et. al., 2020). The patterns of codes captured the depth and meaning of participants past user experience. This combined with the tasks performed on the IVSP during the study allowed for both detailed understanding of preferences and an overarching interpretation of the clinical needs of IVSP innovation.

5.4 | Ethics

Institutional review board approval was obtained, and nurses who met inclusion criteria completed an informed consent which included permission to be videotaped during the qualitative interview process. At the start of each interview, each participant was reminded that participation is voluntary, they can withdraw at anytime and all audio

TABLE 1 Semi-structured interview guide

Initial question	Optional follow-up questions
Which was the most significant thing you learned from your experience here? The more details the better	
What are the major differences for you among the different IV smart pumps? Talking about the pumps you saw today	How do they differ?
Of all the programming you did today, which programming even and on which pump was the most frustrating for you?	Why?
How valuable do you find the use of IV smart pumps in your daily clinical practice?	Can you explain why you feel they are valuable as opposed to hanging to gravity for example?
Do you have an experience with the use of an IV smart pump in your current practice that you would like to share that you have not already discussed?	Something that was good, something that was bad and something that was really useful? If you could change anything what would you change?
What are the best and worst things about using IV smart pumps?	Is there anything else you want to add that you haven't already covered? Worst things for example?
What additional feature would you like to have on an IV smart pump that you would use and why?	How would that impact your daily work?
Is there anything else you would add to a pump?	Maybe the label? A place to put the labels? Expansive information in the library?
Of the two pumps used today which one would you prefer to use and why?	Do you remember what letter it was?
Do you have any additional feedback or comments?	

recordings were confidential. Data and recordings were kept in a secured office on a password protected computer with all personal identifiers removed and anonymous subject IDs assigned. Interviews were conducted in a private, comfortable setting outside of the nurses' regular work hours. Qualitative data were collected one-on-one so that the nurses did not feel 'put on the spot' in front of their colleagues.

6 | RESULTS

6.1 | Participants

Study participants represented an experienced sample of critical care nurses, with details of the demographic provided in Table 3.

6.2 | Themes

The following four themes were identified: appreciation for attractive design features, the need for efficiency, the importance of intuitive use and concern for patient outcomes. Overall, these themes provide evidence that nurses strongly prefer a more usable IVSP interface that integrates safeguards to efficiently improve patient outcomes. In line with Vincent et al. (1998) human factors theoretical framework, these results contribute to our understanding of the complex clinical role that IVSP play and provide insight for technology development from a user perspective. The knowledge provided by these nurses can inform manufacturers, regulatory bodies and researchers about how IVSP are used in real-life clinical situations and transform how users interface with the devices through future IVSP innovation to prevent medication errors.

6.2.1 | Appreciation for attractive design features

The aesthetics of interface features were perceived as helpful for the provision of nursing care. All participants expressed an appreciation of advanced IVSP design features, most notably the touchscreen and smart technology.

> The touchscreen was...BAM right there
>
> (Participant 4).

> The ease of the touchscreen versus touching buttons that potentially get worn out. And then not being able to input a number because you are not on the right pad. But the touchscreen was slick. I like it
>
> (Participant 2).

Nurses also repeatedly emphasized their preference for clean, well-lit screens that were easy to view from a distance. Pumps that had clear displays allowed nurses to more easily identify infusing medications.

> I like the bigger screens because I think that from a distance it's much clearer because the way we use the pumps now we are always kind of labeling things
>
> (Participant 1).

> It was the touchscreen. Visually it was easy to look at
>
> (Participant 6).

Participants also described undesirable design features that included IVSP which were cumbersome and heavy, included too many technical alarms, required too many steps and oftentimes the screen, font or display colour made instructions difficult to follow and programming more challenging.

> The first pump was too big...it was just too big...and too cumbersome...and there were too many instructions
>
> (Participant 1)

Overall, nurses reported touchscreen technology, large and well-lit screens, small size, light weight and fewer alarm features were attractive design features for them.

6.2.2 | The need for efficiency

The second common nursing experience was a preference for an efficient pump. Participants emphasized the need for rapid IVSP programming that did not consume too much of their time.

> And most [of] the time we are thinking quickly in the ICU. I don't have time to mess with the pump too much. I need the pump to be simple
>
> (Participant 6)

> It is very user-friendly... less time-consuming. I just actually loved it, it's going to be awesome to use especially in the ICU [and] ER
>
> (Participant 13).

In addition to saving time in their work, the nurses expressed the importance of efficiency on patient outcomes. Participants closely associated the speed of the IVSP pump with patient safety.

> I don't have time to mess with the pump too much... in the ICU that would be... just... it would be life-threatening
>
> (Participant 6).

> I could walk into a room and program that first pump in like a second. The other one like... my patient would be dead
>
> (Participant 7).

TABLE 2 Codes and resultant themes

Code	Theme
Touchscreen capabilities Visual clarity Bright Readable colours Readable font Lightweight Smaller Bigger screen Capability for multiple meds through one pump Big, heavy, cumbersome Finicky	Appreciation for attractive design features
Fast programming speed Saves time Efficiency is critical Too many steps required More steps is time wasted Channel changing not efficient	Need for efficiency
User-friendly Self-explanatory Minimal instructions required No conscious reasoning	Importance of intuitive processes
IVSP are critical to patient care Many safety features Eliminates errors Less opportunity for error Safer Less second-guessing Still allows critical thinking	Concern for patient outcomes

Overall, participants strongly preferred pumps that allowed them to work quickly. A common experience was that the touchscreen facilitated rapid programming.

> When I looked at that second pump with all the buttons… it was like it shut down my brain so I really… the touchscreen made such a difference in getting it ready to use the pump
>
> (Participant 7).

6.2.3 | The importance of intuitive use

Nurses among this cohort continuously referred to the usability and desirability of IVSP that are intuitive. Nurses perceived pumps to be intuitive when they were 'very user friendly' (Participant 13) and when programming was easy to understand without training or instructions.

> One pump…almost knew what I wanted
>
> (Participant 3).

> [The prototype] was definitely more self-explanatory. I could you know, go through and figure it out pretty fast on my own
>
> (Participant 15).

Overall, participants felt that intuitive, user-friendly features made the IVSP not only easier to use, but also more efficient and safer.

6.2.4 | Concern for patient safety

When describing their experience working with an unfamiliar IVSP, nurses were found to focus heavily on the relationship between the pump and patient safety. Nurses perceived the pump as having a large impact on their ability to provide safe patient care. As described earlier, the need for efficiency was closely linked with safety. A second feature described as vital for patient safety was the drug library. Nurses expressed a preference for drug libraries that were complete and easily accessible.

> The library is very extensive now they're always adding things to the library… yes the library is very helpful
>
> (Participant 1).

> Libraries provide you with the right drip, the right amount of drug, and it's right there
>
> (Participant 3).

Nurses described the role of the drug library in reducing medical errors. A common belief was that the use of IVSP reduces the chance of making a mistake when administrating IV medication.

TABLE 3 Participant demographics

Variables (frequency)	N	%
Gender		
Male	2	13.3
Female	13	86.7
Highest degree		
Associates	2	13.3
Bachelors	10	66.7
Masters	3	20
Primary work shift		
7a.m.–7p.m.	6	40
7p.m.–7a.m.	7	46.7
Other	2	13.3
Current work status		
Full time	11	73.3
Part time	4	26.7
Type of critical care unit		
CCU	1	6.7
MICU	3	20
SICU	2	13.3
Trauma	3	20
Mixed	6	40
Type of hospital		
University teaching	10	66.7
Community	5	33.3
Nursing certification		
CCRN	11	73.3
Other	1	6.7
None	3	20
Which pump would you chose for your clinical practice?		
Pump A	0	0
Pump B	0	0
Prototype	15	100

> [The drug library] takes a lot of the guesswork out. It takes away the opportunity for error
>
> (Participant 2).

> There's just not even a way to measure how valuable they absolutely are. I definitely think it cuts down on user error
>
> (Participant 14).

Several participants articulated the belief that the drug library safeguards against errors by double checking the nurse's work. Nurses preferred a sense of 'double checking' rather than feeling that the machine controlled their programming.

> Great at prompting, okaying, double checking, protecting our patients
>
> (Participant 15).

> If it doesn't allow critical thinking and actual people interaction you are controlled by the machine and I don't like that
>
> (Participant 14).

Efficient programming and extensive, up-to-date libraries were two common features closely tied to patient safety. However, concern for patient care was a theme that consistently emerged throughout the nurses' interviews. Therefore, overall, a major finding was that nursing pump preferences are strongly determined by their belief that the pump features will enable safe, effective and accurate IV administration.

These themes were established through abstraction of the interview content. Further abstraction, however, reveals that nurse participants simply wish to have a more user-friendly, intuitive and streamlined IVSP experience. Although the analysis revealed specific nurse preferences, taking a step back shows the importance of the overall user experience in device design and its translation into bedside use for safer patient care.

7 | DISCUSSION

Medication error is a source of significant risk for hospitalized patients, especially with IV medications which act quickly and can be difficult to reverse (Ding et al., 2015; Fahimi et al., 2015). Building off Vincent et al.'s (1998) application of human factors in a clinical context to reduce error, this study applied a human factors approach by evaluating experienced nurse perspectives of IVSP design. Recognizing the complexity of different factors that lead to adverse events is critical for reducing the rate of errors. Exploring critical care nurses' experiences of using unfamiliar IVSP has provided insight into how IVSP design interface with nursing practice to impact patient care.

Results of this study indicate that nurses strongly associate IVSP design with patient safety. Design features including touchscreen technology, intuitive design that facilitated efficient programming and an extensive, accessible drug library were emphasized as critical IVSP features to reduce medical errors. Notably, participants also expressed concern that some IVSP designs, including those with too many alarms, too many steps and programming that was inefficient, would directly harm patient safety. Excessive alarms leading to alarm fatigue has been found to be a source of stress for clinicians, patients and families which has been found to lead to desensitization of staff and delayed response to alerts (Ohashi et al., 2014). Additionally, past study of programming complexity has demonstrated that inefficient programming with many steps can lead to more opportunity for interruption and longer programming time which can have a clinical impact (Giuliano, 2018b). When describing pumps that were challenging or slow to use, nurses stated, 'the person would have coded' and 'my patient would be dead'. These statements highlight the severe consequences of poorly designed IVSP and are consistent with previous study showing that poor usability can lead to IVSP error (Fan et al., 2014; Giuliano, 2015).

This study provides evidence of the importance of incorporating nursing preferences into IVSP design. The participants' own words provide support for the need for IVSP to be engineered with clinical practice outcomes, intuitive use and efficiency as fundamental design inputs. As highlighted by the FDA in their usability guidelines (FDA, 2016), the best way to improve human device interaction in a critical care setting is for those individuals responsible for designing and producing IVSP to collaborate with practicing end-user nurses. When collaboration occurs between IVSP designers and nurses, safety of the most used medical devices in acute care can be improved with clinical relevance as a priority.

7.1 | Strengths and limitations

This study provides a deep understanding of critical care nurse experiences when interacting with unfamiliar IVSP to complete common medication administration tasks. A limitation to this study includes the use of a relatively homogenous participant group from the Boston, MA area, all of whom were practicing critical care nurses. Although the nurses were all unfamiliar with the IVSP models assigned to them, they are very familiar with IV medication administration, and therefore, a study of nurses with a different level of IVSP expertise may yield different results. Future study may include nurses with no IVSP experience or experience from other care areas. Although the sample size for this study was determined by the needs of the quantitative pilot study, the sample size was adequate for qualitative description study and data saturation was reached. This study was limited to three IVSP models, additional findings about nurses' experiences and preferences could be obtained with a broader selection of pump models.

8 | CONCLUSION

The findings of this qualitative descriptive study support the need for more usable and intuitive-use interfaces in IVSP design that are mindful of relevant clinical practice. The critical care nurse participants expressed dissatisfaction with IVSP that were cumbersome to manipulate, complex to learn and challenging to programme quickly and accurately. Participants preferred to work with the new prototype that was intuitive to use but regardless agreed that use of IVSP in general was necessary for safe patient care. Data like these are important for consideration when IVSP manufacturers and designers are updating existing products or developing new ones. Through heightened awareness of risk associated with IVSP use, nurses must operate IVSP in their clinical setting with purpose and reflection to strive for improved patient safety. Nursing educators and managers should use the results of this study as fuel for staff education initiatives and recognize the high cognitive demand required for IVSP programming, thus reinforcing the need to reduce external distractions during IV medication administration. Given the ubiquitous nature of IVSP in today's acute care environment and with nurses as the primary end-users of IVSP, nurses are in key position to work with manufacturers to help improve IVSP safety and usability. These results can be used to drive much needed innovation of the user interface of IVSP devices. Through joint device development nurses can collaborate with engineers and manufacturers building a more usable and clinically relevant device that places patient safety at the forefront. Although IVSP is one example with a pressing safety need, this collaborative relationship should be used to improve innovation for the development of all devices that are intended for use by clinicians.

DATA AVAILABILITY STATEMENT
The data that support the findings of this study are available from the corresponding author upon reasonable request.

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