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Usability Challenges and Safety Risks of Medical Infusion Pumps: A User-Centered Analysis Across Clinical Roles and Experience Levels in Saudi Arabia

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Background: Medication errors involving intravenous (IV) therapy remain a major patient safety challenge. Evaluating the usability and safety of Medical Infusion Pumps (MIPs) is critical to identifying risk sources and improving clinical practice.

Objective: This study aims to characterize the types, frequencies, and severities of MIP-related medication errors in Saudi Arabia and to identify statistically significant factors associated with these errors.

Methods: A cross-sectional survey was administered to 387 healthcare providers across multiple hospitals. Participants rated the frequency and impact of 26 MIP problems across five domains. Statistical analyses included ANOVA and effect size calculations.

Results: Significant differences were found across job roles for nearly all problem classes ($p < 0.05$). Less experienced users reported significantly higher frequencies of Human Factors issues ($p = 0.024$). Specialty pumps demonstrated significantly higher User Interface problem frequencies compared with traditional pumps ($p = 0.046$). Pump connectivity to Hospital Information Systems (HIS) was also significantly associated with higher perceived problem frequencies across all domains ($p < 0.05$).

Conclusion: The findings highlight critical usability concerns—particularly related to UI design, human factors, and system integration—that significantly impact MIP safety. Targeted training for less experienced users and user-centered design improvements are essential to reducing medication errors.

Keywords: medical infusion pumps, medical errors, usability, risks, safety

Introduction

Medical infusion pumps (MIPs) are fundamental components of modern clinical care, delivering intravenous (IV) fluids, medications, and nutrients across a wide range of patient populations. Their widespread use underscores their clinical value but simultaneously raises concern about an increasing dependence on technologies that continue to introduce safety risks. Despite compliance with engineering and regulatory requirements, infusion pumps remain strongly associated with adverse events, suggesting that existing frameworks may not fully address the complexities of real-world clinical environments and human–machine interaction.[1]

Device recalls and incident reports consistently reveal patterns of preventable harm associated with design flaws, programming challenges, and workflow mismatches. These incidents—some resulting in serious injury or death—highlight systemic shortcomings rather than isolated technical failures. Persistent issues such as incorrect dosage settings and infusion-rate errors point to a fundamental misalignment between pump design and the cognitive and operational demands of clinical workflow.[2] Regulatory initiatives, including FDA summits, continue to underscore the limitations of current mechanisms in preemptively reducing these risks.[3]

At the same time, research demonstrates that smart infusion pumps can offer substantial safety benefits when implemented appropriately. Several systematic reviews have shown reductions in medication administration errors, improved adherence to drug libraries, and decreased rates of high-risk infusion events through automated alerts and decision-support features.[4,5] A recent systematic literature review published in 2025 further found that smart infusion

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pump interoperability significantly reduced medication administration errors in every included study, with improvements in dosing accuracy, automated error interception, and adherence to medication protocols when pump systems were integrated with electronic health records.[6] These findings illustrate that infusion device automation can meaningfully enhance safety, reinforcing the need for a balanced evaluation that considers both risks and benefits.

International regulatory frameworks also emphasize the importance of usability engineering in reducing device-related errors. The US Food and Drug Administration (FDA) requires manufacturers to conduct robust human-factors engineering and validation testing as part of premarket submissions for infusion pumps.[7] Likewise, the IEC 62366 standard specifies usability engineering processes aimed at minimizing use-related hazards and ensuring that device design aligns with clinical workflow and user needs.[8] These standards highlight a global shift toward integrating human-factors principles as core components of medical device safety, further supporting the relevance of examining real-world usability challenges such as those explored in this study.

Despite regulatory advances and documented benefits, the global literature on infusion pump safety remains heavily skewed toward high-income countries. This disparity creates a notable evidence gap regarding device performance, training variability, and user challenges in developing or rapidly evolving healthcare systems. Regions such as Saudi Arabia illustrate this gap clearly, where differences in healthcare delivery models, staffing structures, multilingual clinical teams, and diverse pump brands may influence usability patterns and error risks.[9] The multinational workforce in Saudi hospitals, combined with inconsistent training and variability in device familiarity, further complicates standardization and effective use of MIPs.

Alarm fatigue is another persistent and well-documented challenge across healthcare environments. The high frequency of alerts—many of which are non-actionable—contributes to clinician desensitization, delayed responses, and increased risk of overlooking critical warnings. Although widely recognized, this issue continues to occur across pump models and care settings, highlighting an ongoing disconnect between technical capability and practical usability.[10]

In parallel, the rapid expansion of the global infusion pump market raises additional concerns. While commercial growth is often viewed as a marker of technological advancement, it can reinforce longstanding design issues if usability challenges remain unaddressed.[11] Without corresponding improvements in human-factors integration, training, and workflow alignment, new devices risk perpetuating the same limitations documented over the past decade.

Given these gaps, the present study examines the safety and usability challenges associated with MIPs within Saudi Arabian hospitals from the perspective of healthcare professionals. Rather than focusing solely on technical specifications or isolated incident reports, the study emphasizes lived user experiences and contextual factors—elements that are often underrepresented in regulatory and design discussions. By characterizing error frequency, perceived severity, and contributing factors across different clinical roles and experience levels, this research aims to inform more effective, context-sensitive interventions that enhance both safety and usability in infusion pump use.

Materials and Methods

This study employed a cross-sectional descriptive design to evaluate the usability and safety challenges associated with Medical Infusion Pumps (MIPs) in Saudi hospitals. The aim was to quantify healthcare professionals' perceptions of MIP-related problems and identify contextual factors that contribute to these challenges across diverse clinical environments.

Survey Development and Validation

A structured survey instrument was developed by a multidisciplinary team consisting of biomedical engineers, clinical researchers, and patient safety specialists. The survey was informed by a comprehensive literature review conducted across PubMed, Scopus, and IEEE Xplore using search terms such as "infusion pump errors," "device usability," and "human factors in healthcare technology." From this review, 26 commonly reported MIP problems were identified and categorized into five domains:

- User Interface (UI)
- Software (SW)
- Mechanical (M)
- Electrical (E)
- Human Factors (HF)

These classifications are summarized in Table 1. To establish content validity, five subject-matter experts in clinical engineering and risk management reviewed the draft instrument. A pilot test with 30 healthcare professionals was then conducted to assess the clarity, relevance, and usability of survey items. Feedback from the pilot phase led to minor wording and formatting adjustments. Internal consistency of the final instrument was evaluated using Cronbach's alpha, yielding a reliability coefficient of 0.87, indicating high internal reliability.

Sampling and Participants

A total of 677 healthcare professionals were invited to participate through stratified sampling. Invitations were disseminated via hospital communication channels, professional organization mailing lists, and institutional Email networks. The sampling strategy ensured diversity across:

- Professional roles (physicians, nurses, biomedical engineers)
- Healthcare facility types (public and private; tertiary and secondary)
- Clinical departments (ICU, emergency, operating theatre, general wards).

Inclusion criteria required participants to have direct experience using, monitoring, or managing MIPs. Ultimately, 387 completed responses were obtained and included in the analysis. A formal a priori power analysis was not conducted because the study followed a cross-sectional survey design; however, the final sample exceeds the commonly recommended ratio of 10–20 participants per variable, supporting adequate statistical power for subgroup and multivariable comparisons. This sample size is considered sufficient to provide stable estimates across different roles and experience levels.

Survey Structure

The final survey comprised four components:

1. Demographic Information: Profession, years of experience, hospital type, MIP brands used, HIS integration, and internal error-reporting procedures.
2. Problem Frequency Ratings: Participants rated the frequency of each of the 26 identified problems using a 5-point Likert scale (1 = least frequent; 5 = most frequent).
3. Safety Impact Ratings: Using a parallel 5-point scale (1 = no impact; 5 = remarkably high impact), participants rated the perceived severity of each problem.
4. Open-Ended Feedback: Space for additional comments or suggestions related to MIP usability and safety.

Table 1 Classification of Most Encountered MIPs Problems

Class/ No	UI	SW	M	E	HF
1	Unclear labeling	No audible alarm for a critical problem.	Pump blockage	Battery failures	Select the wrong regimen
2	Screens confuse	Alarm in the absence of problem	Broken part	Fire	Skin allergic
3	Difficult to Read in Different Settings	Pump workflow does not match the user workflow	Bubbles in insulin pumps	Sparks	Inadequate training
4	The instruction manual not clear	Critical MIP features in need of standardization	Tubing kink or crack or blockage	Charring	
5	Navigation between operational modes not clear	Failures in the color light alarm	Reservoirs can leak	Shocks	
6	Difficulties in the manual to know entering and editing of orders and data	Errors in continuous glucose monitor (CGM)	Needles slip		

This structure enabled a risk-weighted assessment of challenges by examining both the likelihood and perceived clinical impact of each problem.

Data Collection Procedures

The survey was administered electronically using a secure, web-based platform. Data were collected between February 2023 and August 2023. Participants accessed the survey via personalized or institution-specific links to ensure broad geographic reach across Saudi Arabia. No identifiable personal or patient information was collected.

Statistical Analysis

Data were analyzed using IBM SPSS (version X). Descriptive statistics (means and standard deviations) were calculated for each of the five problem domains (UI, SW, M, E, HF). Inferential analyses included:

- Cross-tabulations examining relationships between demographic variables and problem ratings.
- One-way ANOVA to evaluate statistically significant differences in frequency and impact across subgroups (job role, experience level, pump type)
- Effect size measures, including Cohen's *d* and partial eta squared (η^2), to assess practical significance beyond *p*-values.

A significance level of $p < 0.05$ was applied. This mixed quantitative approach allowed comprehensive exploration of how user characteristics and device attributes shape perceptions of MIP-related usability and safety challenges.

Results

Participant Characteristics

A total of 387 healthcare professionals from hospitals across multiple cities in Saudi Arabia participated in the study. Of these, 272 (70.3%) were from government hospitals and 115 (29.7%) from private hospitals. Participants represented diverse professional roles and experience levels (Table 2 and 3) and were distributed across several geographic regions (Table 4), supporting the representativeness of the sample across healthcare environments and operational contexts.

Table 2 Distribution of Participants by Job Roles

	Frequency	%
Physician	48	12.4
Nurse or RN	136	35.1
Biomedical Engineer	93	24.0
Internship	27	7.0
Medical Student	57	14.7
Other	26	6.7
Total	387	100.0

Table 3 Distribution of Participants by Years of Experience

Category	Freq	%
Less 1 year	135	34.9
1 to 5 years	137	35.4
6 to 10 years	52	13.4
11 to 15 years	42	10.9
16 years or more	21	5.4
Total	387	100.0

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Table 4 Geographical Distribution of Participants by City

City	No of Participants
AlHasa	21
Al Khobar	43
Qateef	42
Alriyadh	73
Dammam	111
Jeddah	16
Jubail	16
Other	65
Total	387

Overview of Problem Class Ratings

Table 5 provides an initial summary of how participants rated the five major MIP problem classes—User Interface (UI), Software (SW), Mechanical (M), Electrical (E), and Human Factors (HF)—in terms of both perceived frequency and safety impact. These baseline ratings help contextualize subsequent subgroup analyses.

Influence of Job Role

As shown in Table 5, statistically significant differences ($p < 0.05$) were identified across job roles for both the frequency and impact of MIP-related problems. Different professional groups evaluated each problem class differently, highlighting the importance of incorporating role-specific needs into MIP design, usability considerations, and training strategies.

Influence of Experience Level

Findings presented in Table 6 demonstrate that users with fewer years of professional experience reported higher frequencies and greater safety impacts for several problem categories. Differences reached statistical significance in

Table 5 Mean Frequency and Impact Ratings Across Problem Domains

Frequency/Impact (mean ± SD)	Physician (48)	Nurse or RN (136)	Technician (93)	Internship (27)	Student (57)	Other (26)	p-value 10^{-3}
Frequency UI	1.799±0.7	2.275±0.9	2.106±0.7	2.111±0.8	2.395±0.7	2.16±0.9	2
Impact UI	1.837±0.8	2.385±0.9	2.391±0.9	2.173±0.9	2.845±0.8	2.314±1.1	1
Frequency SW	1.778±0.8	2.256±1.0	2.083±0.9	1.986±0.7	2.322±0.8	2.032±0.8	13
Impact of SW	2.069±1.0	2.441±1.0	2.6290±1.1	2.2778±1.0	2.892±1.1	2.308±1.1	2
Frequency M	1.8889±1.0	2.186±1.0	2.419±0.9	2.173±0.8	2.503±0.8	2.058±1.0	6
Impact M	2.042±1.2	2.385±1.1	2.850±1.1	2.296±1.1	2.968±1.0	2.218±1.3	1
Frequency E	1.492±0.9	2.041±1.1	2.000±0.9	1.830±0.8	2.000±0.9	1.931±1.0	32
Impact E	1.850±1.2	2.229±1.2	2.832±1.4	2.133±1.2	2.912±1.3	2.277±1.2	1
Frequency HF	1.806±1.0	2.061±1.1	2.176±0.9	2.185±0.6	2.468±0.9	2.051±0.9	23
Impact HF	2.125±1.2	2.302±1.2	2.692±1.2	2.654±1.0	3.088±1.2	2.308±1.1	1

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Table 6 Impact of Experience on Frequency/Impact of MIP Problems

Frequency/Impact (mean ± SD)	Less Than 1 Year (135)	1 to 5 Years (137)	6 to 10 Years (52)	11 to 15 Years (42)	16 Years or More (21)	p-value 10^{-3}
Frequency UI	2.207±0.7	2.128±0.8	2.289±1.0	2.123±0.8	2.071±0.9	679
Impact UI	2.439±0.9	2.319±0.9	2.558±1.1	2.139±0.8	2.190±1.0	15
Frequency SW	2.207±0.8	2.101±0.9	2.128±1.0	2.068±0.9	1.960±0.7	710
Impact of SW	2.606±1.0	2.501±1.1	2.407±1.1	2.309±1.1	2.167±1.0	305
Frequency M	2.370±0.9	2.238±1.0	2.093±1.0	2.183±0.7	1.937±0.9	179
Impact M	2.701±1.1	2.481±1.2	2.455±1.2	2.409±0.9	2.040±1.0	102
Frequency E	2.040±1.0	1.910±1.0	1.785±1.1	2.024±0.9	1.619±1.0	260
Impact E	2.652±1.3	2.418±1.4	2.150±1.3	2.267±1.1	2.000±1.2	58
Frequency HF	2.289±0.9	2.095±1.0	1.776±1.0	2.206±1.0	1.968±1.0	24
Impact HF	2.724±1.1	2.520±1.3	2.224±1.4	2.349±1.1	2.175±1.2	53

the Human Factors (HF) domain. These results suggest that early-career healthcare professionals may perceive increased vulnerability to MIP-related errors, underscoring the potential value of structured orientation and consistent supervision during the early stages of practice.

Impact of MIP Connectivity

The influence of Hospital Information System (HIS) connectivity was examined in Table 7 by cross-tabulating responses ("Yes," "No," "Not sure") with frequency and impact ratings. Significant differences emerged in several areas, indicating that HIS integration may shape how users recognize, interpret, or report device problems. These findings highlight both the benefits and complexities associated with connected pump systems.

Table 7 Comparison of Problem Ratings by HIS Connectivity

Frequency/Impact (mean ± sd)	YES (176)	NO (87)	Not Sure (124)	p-value 10^{-3}
Frequency UI	2.281±0.9	1.900±0.7	2.212±0.7	1
Impact UI	2.463±0.9	2.040±0.9	2.4583±0.9	1
Frequency SW	2.303±0.9	1.800±0.8	2.117±0.9	1
Impact of SW	2.638±1.0	2.155±1.1	2.503±1.1	3
Frequency M	2.366±0.9	1.958±0.9	2.268±1.0	4
Impact M	2.617±1.1	2.339±1.2	2.518±1.2	185
Frequency E	2.044±1.0	1.717±0.9	1.932±1.0	41
Impact E	2.449±1.3	2.301±1.3	2.476±1.4	604
Frequency HF	2.165±1.0	1.893±0.8	2.231±1.0	37
Impact HF	2.515±1.2	2.287±1.1	2.672±1.3	78

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Traditional vs Specialty MIPs

As summarized in Table 8, most comparisons between Traditional and Specialty infusion pumps did not yield statistically significant differences. However, Specialty pumps showed a significantly higher frequency of User Interface (UI) problems (p = 0.046), pointing to a potential area for targeted usability enhancements in devices designed for more complex therapies.

Pump Type Variation

Table 9 details problem ratings across specific MIP types, including syringe, PCA, and elastomeric pumps. Although most differences were not statistically significant, PCA and elastomeric devices showed higher reported frequencies for certain issues. These trends emphasize the importance of tailoring device training and design improvements to the unique characteristics of each pump type.

Table 8 Comparison of Traditional vs Specialty MIPs Problem Class

	Traditional (306)	Specialty (81)	p-value 10^{-3}
Frequency UI (mean ± SD)	2.132±0.7	2.329±1.0	46
Impact UI (mean±sd)	2.375±0.9	2.333±1.0	717
Frequency SW	2.093±0.9	2.274±1.0	103
Impact of SW	2.499±1.1	2.438±1.1	657
Frequency M	2.261±0.9	2.171±1.0	438
Impact M	2.550±1.1	2.420±1.2	368
Frequency E	1.931±1.0	1.948±1.1	892
Impact E	2.489±1.3	2.180±1.3	60
Frequency HF	2.131±0.9	2.103±1.2	822
Impact HF	2.562±1.2	2.33±1.3	134

Table 9 Cross Tabulation of MIP Problem Classes by Pump Type

Frequency/Impact (mean ± SD)	NA (141)	Syringe (138)	Disposable (9)	Large (31)	Elastomeric (4)	Other (34)	Enteral (6)	PCA (8)	Insulin (16)	p-value 10^{-3}
Frequency UI	2.289±0.8	2.072±0.7	2.240±0.6	2.124±0.7	2.500±1.3	2.274±1.1	1.750±0.5	2.208±0.7	1.93±0.6	266
Impact UI	2.491±1.0	2.321±0.8	2.352±1.1	2.23±0.9	2.67±1.5	2.35±1.1	1.69±0.5	2.15±0.6	2.24±0.9	442
Frequency SW	2.22±0.9	2.06±0.9	2.46±0.7	1.9±0.7	2.5±1.3	2.13±1.0	2.3±0.6	1.9±1.0	2.17±0.8	519
Impact of SW	2.55±1.1	2.48±1.1	2.5±0.7	2.30±0.9	2.46±1.4	2.41±1.1	2.67±0.5	2.1±1.0	2.6±1.2	943
Frequency M	2.35±1.0	2.24±0.9	2.5±0.5	1.93±0.8	2.58±1.4	2.24±1.1	1.83±0.5	1.83±1.0	2.05±1.0	266
Impact M	2.56±1.2	2.57±1.1	2.57±0.5	2.19±1.0	2.62±1.5	2.62±1.2	2.17±0.6	2.0±1.1	2.6±1.4	714
Frequency E	2.08±1.0	1.86±0.9	2.2±0.7	1.75±0.8	2.6±1.7	1.86±1.2	1.90±0.4	1.35±1.1	1.78±1.1	198
Impact E	2.5±1.3	2.5±1.3	2.3±1.0	2.17±1.1	2.3±1.7	2.30±1.4	2.9±1.0	1.55±1.2	2.19±1.5	507
Frequency HF	2.18±1.1	2.06±0.9	2.33±0.5	2.13±0.8	2.67±1.7	2.1±1.2	2.38±0.6	1.83±1.3	2.06±1.1	876
Impact HF	2.49±1.3	2.56±1.2	2.81±1.0	2.39±1.0	2.50±1.6	2.5±1.4	2.50±0.4	2.08±1.6	2.54±1.4	979

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Alert and Notification Types

The analysis in Table 10 explores how different alert modalities—such as visual cues, audible tones, and numerical displays—affect perceptions of problem frequency and impact. No single alert type was strongly associated with higher error belief, but the variation in responses indicates differences in how alerts are interpreted, reinforcing the need for clearer and more standardized alert mechanisms.

Error Reporting Mechanisms

Table 11 examines how reporting methods (manual reporting, HIS-based reporting, and others) relate to perceived MIP issues. Although between-group differences were not statistically significant, devices integrated with HIS showed the highest frequencies and impacts, potentially due to improved visibility and more systematic capture of device-related issues.

Table 10 Impact of Different Alert Types on MIP Problem Frequency and Impact

Frequency/Impact (mean ± SD)	Alarm Tone (282)	Light Colored Alerts (40)	Operator Alerts (INOP) (21)	Numeric Flashes (11)	Limits Highlights (19)	Other (14)	p-value 10^{-3}
Frequency UI	2.15±0.8	2.42±0.8	2.08±0.9	2.41±1.1	2.20±0.7	1.90±0.8	225
Impact UI	2.34±0.9	2.69±0.8	2.079±0.8	2.636±1.0	2.386±1.0	2.095±0.9	97
Frequency SW	2.12±0.9	2.23±1.0	2.12±0.7	2.67±0.9	2.07±0.8	2.07±0.9	216
Impact of SW	2.48±1.1	2.44±1.0	2.55±1.1	2.94±1.0	2.44±1.0	2.3±1.1	786
Frequency M	2.26±0.9	2.36±1.0	2.064±0.9	2.55±1.1	2.0±0.9	1.99±1.0	423
Impact M	2.515±1.2	2.55±1.1	2.58±1.3	2.95±1.2	2.3±1.1	2.476±1.2	789
Frequency E	1.88±1.0	2.135±1.1	2.028±1.0	2.49±1.1	1.916±1.1	1.86±1.0	292
Impact E	2.38±1.3	2.480±1.2	2.5±1.3	3.309±1.2	2.273±1.2	2.58±1.4	317
Frequency HF	2.3±1.0	2.2±0.9	2.27±1.0	2.24±1.0	2.12±0.8	2.07±0.9	947
Impact HF	2.497±1.3	2.45±1.2	2.746±1.2	2.45±1.0	2.47±1.0	2.79±1.2	895

Table 11 Effect of Reporting Methods on Frequency and Impact of MIP Problems

Frequency/Impact (Mean ± SD)	Manual Record (116)	Electronic Through The Hospital Information System (193)	Other (21)	N/A (57)	p-value 10^{-3}
Frequency UI	2.10±0.7	2.23±0.8	2.25±0.7	2.10±0.9	513
Impact UI	2.23±0.8	2.466±0.9	2.33±0.6	2.318±1.1	175
Frequency SW	2.108±0.8	2.176±0.9	2.174±0.9	2.00±0.9	625
Impact of SW	2.33±1.0	2.6±1.2	2.47±0.9	2.45±1.2	253
Frequency M	2.1609±1.0	2.36±0.9	2.0±1.0	2.08±0.9	70
Impact M	2.38±1.2	2.67±1.1	2.26±1.1	2.38±1.2	81
Frequency E	1.86±1.0	2.03±1.0	1.80±1.1	1.83±1.0	314
Impact E	2.26±1.3	2.5969±1.3	2.23±1.4	2.24±1.3	84
Frequency HF	2.0±1.0	2.210±1.0	2.1±1.0	2.02±1.0	391
Impact HF	2.43±1.2	2.6±1.2	2.31±1.2	2.44±1.1	541

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Table 12 Summary of Statistical Significance for Factors Affecting MIP Problems

Table	Category	Problem Type	Significance of Frequency	Significance of Impact	Notes
5	Job	All Types (UI, SW, M, E, HF)	Mostly significant	Mostly significant	Nurses and students
6	Experience Level	All Types (UI, SW, M, E, HF)	Mostly Not Significant	Mostly Not Significant	HF Problems Frequency was Significant (p=0.024)
7	Connectivity	Yes, No, not sure	All are significant	M, E, HF impact is not significant.	
8	Traditional vs Specialty	UI	Significant (p=0.046)	Not Significant (p=0.717)	UI problems more frequent in Specialty MIPs
9	Type of MIP	UI	Not Significant	Significant	Elastomeric and PCA pumps most problematic
10	Type of Alert	All Types (UI, SW, M, E, HF)	Not Significant	Not Significant	Close to significant for some impact measurements
11	Reporting method	All Types (UI, SW, M, E, HF)	Not Significant	Close to Significant	Confusing screens were notably problematic

Summary of Statistically Significant Findings

Table 12 consolidates all statistically significant outcomes across subgroups. Significant associations were observed for job role, experience level, and certain MIP types. These findings provide actionable insights to inform targeted training, procurement decisions, and safety strategies aimed at enhancing MIP usability and clinical performance.

Discussion

Despite growing attention to patient safety and advances in healthcare technology, medication errors and usability issues with medical infusion pumps (MIPs) continue to present substantial risks in clinical practice.[12,13] Many of these issues stem from design limitations, particularly when pump development relies on single-method approaches such as observational studies or heuristic evaluations. More reliable and user-centered designs can be achieved through integrated, multi-method approaches.[14]

This study sought to characterize how healthcare professionals perceive MIP-related problems and to highlight areas requiring improvement. The results demonstrate that user experience and training levels significantly influence perceived frequency and severity of MIP issues. These findings are consistent with earlier work emphasizing the role of usability and human factors in medication administration errors.[15–18] For example, PCA and elastomeric pumps have repeatedly been shown to be more error-prone due to complex programming steps and unintuitive interfaces.[18]

Our results also showed that less experienced users reported higher frequencies and severities of user interface (UI) problems, supporting prior evidence that clinical experience reduces susceptibility to device-related errors.,[19–21] This underscores the need for ongoing, tailored training programs to support safe pump use. Another important finding relates to the integration of MIPs with Hospital Information Systems (HIS). Although HIS connectivity can enhance treatment personalization and safety,[22,23] it also introduces new error pathways and workflow complexity.[24] The significant associations observed between HIS connectivity and perceived problem frequency reinforce the importance of phased implementation strategies accompanied by comprehensive training.

The study further found that specialty pumps are more often associated with UI-related issues than traditional pumps (p = 0.046), likely reflecting their more advanced and intricate functionalities. This is consistent with earlier reports indicating that specialty and high-acuity devices require more sophisticated training and interface design.[17] Improvements in intuitive design and human-factors–driven UX methodologies remain essential to reducing errors and improving usability.[12,17,19,24]

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To contextualize these findings, it is important to compare them with provider survey–based research examining smart infusion pump implementation. Prior surveys conducted in the United States and Europe have reported similar challenges, including high alert burden, difficulties with UI navigation, and variable compliance with drug libraries.[25,26] Nurses and less experienced clinicians were consistently identified as facing more difficulty with advanced pump functions—patterns that closely resemble those observed in our sample.

Other provider surveys and evaluation studies also document both challenges and benefits associated with smart pump implementation. These reports confirm that issues such as interface complexity and alert overload are common across settings,[25,26] but they also highlight substantial benefits when smart pumps and interoperability features are appropriately implemented. Improved compliance with drug libraries, enhanced workflow efficiency, reduced programming deviations, and increased productivity have been widely reported through health-system evaluations.[27–29] Optimized pump–EHR interoperability has been shown to reduce non-actionable alerts, minimize workarounds, and support more consistent clinical practice.[28,30] From an operational perspective, recent economic analyses demonstrate that interoperability can improve medication safety, enhance charge capture, and reduce system-level inefficiencies.[31] To date, no large-scale provider surveys examining smart infusion pump use have been conducted in the Middle East, underscoring the regional relevance of the present work.

When used appropriately, smart infusion pump technologies offer important operational and safety benefits that extend beyond error reduction. Studies have demonstrated that successful implementation can yield high drug-library compliance rates—often exceeding 85–95%—improved dosing accuracy, and more efficient pump programming workflows.[32,33] Clinicians also report reduced time spent on manual checks, faster workflow transitions in high-acuity contexts, and fewer non-actionable alerts due to optimized drug library logic.[34,35] These benefits highlight how training quality, system governance, and workflow alignment play critical roles in realizing the full value of smart pump technologies.

International regulatory frameworks reinforce this perspective by emphasizing usability engineering as a core element of device safety. The US Food and Drug Administration (FDA) requires manufacturers to provide evidence of rigorous human-factors engineering and usability validation during pump development.[7] Similarly, the IEC 62366 standard outlines structured usability engineering processes aimed at identifying and mitigating use-related hazards in medical devices.[8] These frameworks highlight the inseparability of device performance and human-machine interaction and underscore the need for continuous evaluation of real-world usability issues.

Finally, the findings of the present study support the importance of strong institutional guidelines and continuous quality-assurance practices. Standardized protocols, structured training programs, and robust reporting systems are essential to capturing both human errors and systemic weaknesses.[36] Trends in FDA data illustrate the scale of these concerns; more than 23,000 malfunction and injury reports related to large-volume IV smart pumps were submitted between 2015 and 2017.[37] Many incidents involved alert overrides and incomplete drug libraries—issues frequently linked to UI design limitations and workflow mismatches.[38] Collectively, the evidence suggests that improving MIP safety requires a multifaceted approach that combines user-centered design, structured training, thoughtful HIS integration, and institution-level governance. Without such strategies, even technologically advanced infusion systems risk undermining patient safety.[39,40]

Conclusion

The study's findings highlight the need for focused interventions to address the usability challenges associated with Medical Infusion Pumps (MIPs). Targeted training is essential, particularly for less experienced staff, who reported higher frequencies of errors. Training should be tiered by experience level and emphasize hands-on practice, troubleshooting, and risk awareness, supported by periodic refresher sessions to reinforce safe operation.

Improvements in device design are also necessary. Specialty pumps—such as PCA and elastomeric devices—require clearer, more intuitive interfaces. Incorporating user-centered design principles and providing real-time feedback features (eg, prompts or alerts) can help reduce recurring errors and support safer decision-making.

Alert systems should be optimized to distinguish critical from non-critical notifications, reducing alert fatigue and improving response accuracy during demanding clinical situations.

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Finally, proactive monitoring is needed. Continuous evaluation, incident reporting, and structured feedback loops should guide ongoing enhancements in both device design and training strategies. Implementing these recommendations can reduce MIP-related risks, enhance efficiency, and improve overall patient safety.

Recommendations

The study's findings highlight the need for focused interventions to address the usability challenges associated with Medical Infusion Pumps (MIPs). Targeted training is essential, particularly for less experienced staff, who reported higher frequencies of errors. Training should be tiered by experience level and emphasize hands-on practice, troubleshooting, and risk awareness, supported by periodic refresher sessions to reinforce safe operation.

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Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

During the preparation of this work the authors used ChatGPT in order to improve language and readability, with caution. After using this tool/service, the authors reviewed and edited the content as needed and takes full responsibility for the content of the publication.

Ethics and Consent Statements

Imam Abdulrahman bin Faisal Internal Review Board (IRB; IRB-2023-07-354) approved the project. All human participants provided their consent before starting.

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