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INTEGRATIVE REVIEW OF THE LITERATURE

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ALARM FATIGUE IN INFUSION PUMPS IN THE PEDIATRIC CONTEXT: INTEGRATIVE REVIEW

Fadiga de alarmes em bombas de infusão no contexto pediátrico: revisão integrativa

Fatiga de alarma en bombas de infusión en el contexto pediátrico: revisión integrativa

Elizandra Cassia da Silva Oliveira[1], Juliana da Rocha Cabral[2], Felicialle Pereira da Silva[3], Regina Célia de Oliveira[4]

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ABSTRACT

Objective: to identify the causes of alarm fatigue in studies of infusion pump usability in pediatric intensive care. **Methods:** an integrative review was carried out in the LILACS, SciELO, IBECS, SCOPUS and MEDLINE databases. **Results:** 1,164 publications were identified and six primary studies were selected that emerged in two themes: understanding the causes of the infusion pump alarms that consisted of: incomplete drug library, absolute and strict relative limits, lack of preparation protocol and medication administration, employee vacation period; and measures that can prevent fatigue from your alarms. **Conclusion:** the causes of alarm fatigue involve low user interaction with the equipment, inadequate work processes and low investment in preventive measures for its occurrence The safe use of infusion pumps requires a team to monitor their practices and act by promoting changes in the work context.

Descriptors: Infusion pumps; Pediatric intensive care units; Ergonomics; Clinical alarms; Biomedical technology assessment.

1 Nurse, PhD in Nursing from the University of Pernambuco and State University of Paraíba. Recife - Pernambuco - Brazil. https://orcid.org/0000-0002-4785-4375

2 Nurse, PhD student of the Associate Program of Graduate Studies in Nursing from the University of Pernambuco and State University of Paraíba. Recife - Pernambuco - Brazil. https://orcid.org/0000-0003-3827-996X

3 Nurse, PhD in Neuropsychiatry and Behavioral Sciences from the Federal University of Pernambuco, Adjunct Professor at the University of Pernambuco. Recife - Pernambuco - Brazil. https://orcid.org/0000-0002-2805-7506

4 Nurse, Post-Doctorate, Professor of the Associate Program of Post-Graduation in Nursing, Universidade de Pernambuco and Universidade Estadual da Paraíba. Recife - Pernambuco - Brazil. https://orcid.org/0000-0002-6559-5872

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Alarm fatigue in infusion pumps in the pediatric context: integrative review

RESUMO

Objetivo: identificar as causas da fadiga de alarmes em estudos de usabilidade de bomba de infusão em terapia intensiva pediátrica. **Métodos**: realizou-se uma revisão integrativa nas bases de dados LILACS, SciELO, *IBECS,* SCOPUS e MEDLINE. **Resultados**: foram identificadas 1.164 publicações e selecionados seis estudos primários que emergiram em duas temáticas: compreender as causas dos alarmes da bomba de infusão que constou: biblioteca de fármacos incompleta, limites absolutos e relativos rígidos, falta de protocolo de preparo e administração de medicação, período de férias dos funcionários; e as medidas que podem evitar a fadiga de seus alarmes.**Conclusão**: as causas da fadiga de alarmes envolvem baixa interação do usuário com o equipamento,processos de trabalhos inadequados e baixo investimento em medidas preventivas para sua ocorrencia. A utilização segura de bombas de infusão demanda uma equipe que monitore suas práticas e atue promovendo mudanças no contexto de trabalho.

Descritores: Bombas de infusão; Unidades de terapia intensiva pediátrica; Ergonomia; Alarmes clínicos; Avaliação da tecnologia biomédica.

RESUMEN

Objetivo: identificar las causas de la fatiga de alarma en estudios de usabilidad de bombas de infusión en cuidados intensivos pediátricos. **Métodos**: se realizó una revisión integradora en las bases de datos LILACS, SciELO, IBECS, SCOPUS y MEDLINE. **Resultados:** se identificaron 1.164 publicaciones y se seleccionaron seis estudios primarios que surgieron en dos temas: comprender las causas de las alarmas de la bomba de infusión que consistían en: biblioteca de medicamentos incompleta, límites relativos absolutos y estrictos, falta de protocolo de preparación y administración de medicamentos, período de vacaciones de los empleados; y medidas que pueden prevenir la fatiga de sus alarmas. **Conclusión:** las causas de la fatiga de las alarmas involucran baja interacción del usuario con el equipo, procesos de trabajo inadecuados y baja inversión en medidas preventivas para su ocurrencia. El uso seguro de las bombas de infusión requiere que un equipo monitoree sus prácticas y actúe promoviendo cambios en el contexto de trabajo.

Descriptores: Bombas de infusión; Unidades de cuidados intensivos pediátricos; Ergonomía; Alarmas clínicas; Evaluación de tecnología biomédica.

INTRODUCTION

Alarms in Medical Assistive Equipment (MES) are barriers that can minimize human error and prevent patient safety risk, thus identifying incorrect use of the equipment, or changes in the patient's clinical status; requiring immediate corrective action. [1] In the context of pediatric patient safety, these alarms represent an alert to the "holes" in Reason's Swiss cheese model.[2]

On the subject, studies reveal that in Intensive Care Units (ICU), the number of alarms can vary from 100 to more than 350; where the healthcare professional is exposed per work shift, to more than a thousand alarms.[3] It can be seen that when activated in excess, professionals become insensitive to attending to them, configuring alarm fatigue and allowing relevant alarms to be ignored and/or silenced.[4]

The literature reveals that alarms are evaluated by professionals as irritating, disturbing to the patient, promoting excessive noise, and causing interruptions in workflow.[3-4] Because of this, alarms are often violated, out of range, or reduced in volume.[5] Alarm concerns have been on the Emergency Care Research Institute's (ECRI) 2011,2014,2015,2016,2018 and 2019 "Alarm Hazards" list of the TOP 10 health hazards.[6] This is a major challenge for healthcare professionals in their care practices.

When using an AMS, human-equipment interaction is essential, since the user needs to configure the equipment in order to guarantee the functionality of its alarms, and for his actions to be directed based on the understanding of these alarms.[7] This interaction can be evaluated through the usability of the equipment, and by the way this product can be used by specific professionals to achieve specific goals with effectiveness, efficiency, and satisfaction in a particular context of use.[8] Thus, the AMS should be understood as equipment that is easy to learn and use in care practice.

Among many pieces of equipment in the pediatric ICU, the infusion pump (BI) is a widely used AIM, and is currently an essential ally of the nursing team in the process of administering fluids and medications safely. The incidence of medication errors and adverse events in children is two to three times higher than in adults. Drug doses in children are calculated by time and weight, in addition to the frequent administration of high surveillance or off-label medications continuously,[9] thus requiring greater usability of the BI by its users.

Given the vulnerability of pediatric patients in the ICU, this study highlights the importance of the equipment in the qualification of health care and patient safety. The fallacies and costs in technologies implemented without evaluating their impact on the real work environment have in the usability evaluation, answers to minimize adverse events and risks to patients and health team.

In this context, a better understanding of usability in BI will enable improvements in human-equipment interaction, resulting in greater user satisfaction and, consequently, an effective, efficient, and safe nursing care. In view of this, this study aimed to identify the causes of alarm fatigue in usability studies of pediatric intensive care infusion pumps.

METHODOLOGY

This is an integrative literature review, with the purpose of systematically synthesizing research results with various methodological approaches available in the scientific environment, aiming at a broad understanding of a specific theme and allowing the incorporation of these findings in clinical practice. This method is composed of six steps that include: guiding question of the review; selection of the study sample; categorization and evaluation of studies; interpretation of results and synthesis of knowledge.[10]

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The PICO (acronym for patient, intervention, comparison, outcomes) strategy was used to develop the research question of the integrative review.11 Thus, this study sought to answer the following question: what are the causes of alarm fatigue in usability studies of pediatric intensive care infusion pumps? In this, the first element of the strategy (P) infusion pump; the second (I), assess usability; and the fourth element (O) prevent its alarms fatigue. It is emphasized that, depending on the review method, not all elements of the PICO strategy are employed. In this integrative review, the third element (C) comparison, was not used.

The search was conducted by two researchers independently, the collection period was from November to December 2020, in the databases of Latin American and Caribbean Literature on Health Sciences (LILACS), Scientific Electronic Libray Online (SciELO), Spanish Bibliographic Index in Health Sciences (IBECS), Medical Literature Analysis and Retrieval System Online (MEDLINE) via Pubmed and Scopus, available directly from the databases' websites or via the Capes Portal, with a time limit between January 2009 and January 2020.

The usability theme is widely approached in developed countries, but we did not get any results registered in the Health Science Descriptors (DeCS) or Medical Subject Headings (MeSH). The controlled descriptors and keywords were the following: (a) PubMed, Scopus and IBECS: Infusion Pumps, Intensive Care Units, Pediatric, Ergonomics and Clinical Alarms (MeSH);Infusion Pump, Pediatric Intensive Care Units, Ergonomic and Clinical Alarm(keywords); (b)LILACS and Scielo: Infusion Pumps, Pediatric Intensive Care Units, Ergonomic and Clinical Alarms (Health Sciences Descriptors); Pediatric Intensive Care Unit Infusion Pump, Ergonomic Analysis and Alarms (keywords).

For each database, a search strategy was developed with the controlled descriptors and key words (different crossings).

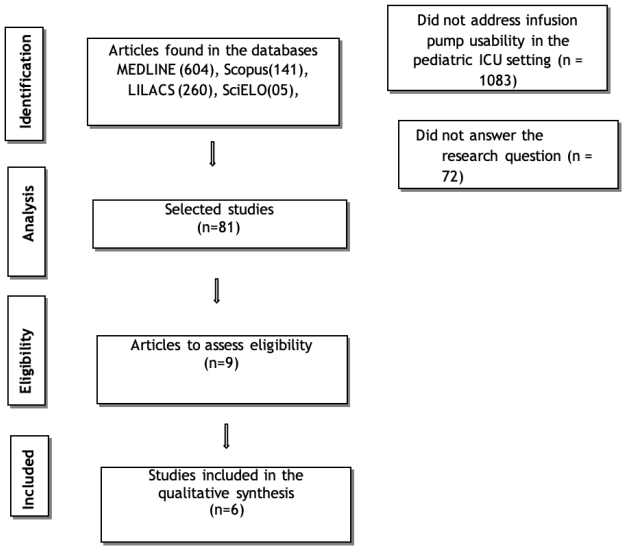
The search strategy used in PubMed, Scopus and IBECS was: 1) Infusion Pumps OR Infusion Pump AND Intensive Care Units, Pediatric OR Pediatric Intensive Care Units, 2) Infusion Pumps OR Infusion Pump AND Ergonomics OR Ergonomic 3) Infusion Pumps OR Infusion Pump AND Clinical Alarms OR Clinical Alarm. LILACS and Scielo was : 1)Infusion Pumps or Infusion Pumps AND Pediatric Intensive Care Units OR Intensive Care Unit, 2) Infusion Pumps or Infusion Pumps AND Ergonomics OR Ergonomic Analysis, 3) Infusion Pumps or Infusion Pumps AND Clinical Alarms OR Clinical Alarms.

Inclusion criteria were: articles about usability of infusion pumps in pediatric intensive care, in Portuguese, Spanish or English. We excluded traditional literature reviews, secondary studies (systematic review), letter-answer and editorials; and studies that presented only quantitative data on the number of alarms per shift and/or sector.

The selection of studies was performed according to the PRISMA12 (Preferred Reporting Items for Systematic Review and Meta-Analyses) diagram. In the database search, 1,164 potentially eligible publications were identified (PubMed=604, Scopus=141, IBECS=154, LILACS=260, Scielo= 5). In the first analysis, after reading the title and abstract of the primary studies; articles that did not address infusion pump usability in the pediatric ICU setting were excluded (n=1083). In the second analysis, by reading the articles in their entirety (n=81), 75 articles were excluded for not answering the research question. The analyses were developed independently by two reviewers. Thus, the integrative review sample was composed of six primary studies, according to (Figure 1).

The six articles were read and analyzed in full. For data collection and synthesis an instrument was prepared with the variables title, journal, year, impact factor according to the Journal Citation Reports (JCR), objectives, and results. The presentation of the results and discussion of the data obtained was descriptive, allowing the reader to evaluate the applicability of the integrative review in order to achieve the objective of this method.

Figure 1 - Flowchart of the process of the selected articles according to the PRISMA model. Recife, PE, Brazil, 2019**.**



Source: authors

RESULTS AND DISCUSSION

The six studies included in this review were all from Spain. There was no evidence of productions in Brazil. The descriptive study type corresponded to (100%) of the sample. The journals of the published articles had a high impact factor, ranging from 0.912 to 3.210. As for the authors, there were physicians, nurses and pharmacists (Chart 1).

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Table1 - Distribution of studies according to: title, journal, year, impact factor, objectives, results and conclusion. Recife, PE, Brazil, 2019.

Article Title	Journal/ Year/ Impact Factor	Study Type	Objective(s)	Results
Risks in the implementation and use of Smart pumps in a pediatric intensive Care unit: application of the failure Mode and effects analysis	International Journal of Technology Assessment in Health Care, 2014 0.912	Descriptive study	Identify risk points at different stages of the smart infusion pump implementation process to prioritize improvement measures.	Periodic reviews of the drug library medications, development of supporting documents, and the inclusion of training were the identified risk points.
Smart pump alerts: All that glitters is not gold	International journal of medical informatics, 2011 3.210	Descriptive study	Evaluate the results of using smart infusion pumps in their initial phase and assess the significance and practical implications of the alarms issued.	By analyzing the triggered alarms, it was possible to detect problems such as the need to increase user training, readjust limits that did not correspond to clinical practice, correct errors in editing the drug library
Implementation of smart pumps technology in a pediatric intensive care unit	Health Informatics Journal, 2015 3021	Descriptive study	Describe the process of implementing the smart pump in a Pediatric Intensive Care Unit (PICU) and present the most relevant infusion-related programming errors that were prevented.	Vacation replacement and medication administration periods were significantly associated with a higher number of infusion-related scheduling errors.
Developing a drug library for smart pumps in a pediatric intensive care unit	Artificial Intelligence in Medicine, 2011 2.879	Descriptive study	Describe the process of developing a specific drug library for a Pediatric Intensive Care Unit and the main factors to avoid programming errors.	Lack of adherence to protocols, errors in editing the limits of specific drugs, incorrect scheduling of infusions are all factors that can cause a high number of unnecessary alarms.
Impact of implementing smart infusion pumps in a pediatric intensive care unit	American Journal of Health-System Pharmacy, 2013 1.969	Descriptive study	To investigate the impact of smart infusion pumps in intercepting errors in scheduling IV drug administrations in a Pediatric Intensive Care Unit (PICU).	92 alarms were associated with programming errors that led to cancellation or reprogramming of the infusion process. About 97% of the errors resulted from user programming of doses or infusion rates above the strict limits defined in the drug library.
Administración segura de medicamentos intravenosos en pediatría: 5 anos ˜ de experiencia de una Unidad de Cuidados Intensivos Pediátricos con bombas de infusión inteligentes	Medicina intensiva, 2016 1.231	Descriptive study	To estimate the impact of the deployment of smart infusion pumps in a pediatric intensive care unit on the number and type of administration errors intercepted.	The ratio number of alerts/ scheduled infusions was 0.76%, and 68% of alerts by relative limit were ignored.

Source: authors.

The scientific production found on the causes of alarm fatigue in usability studies of infusion pumps in pediatric intensive care is incipient according to the inclusion criteria of this review. Furthermore, the studies found in this research approach infusion pumps, also known as "smart pumps", still little used in the Brazilian hospital setting.

There is a lack of guidelines that prioritize the patient's clinical needs and the prevention of adverse events associated with the high cost of implementing smart infusion pumps, which leads us to believe that there will still be a long time before this technology is used in our daily lives. As for the cost-effectiveness studies between the use of infusion pumps with drug libraries and conventional infusion pumps to reduce adverse events, it was shown that although the latter has the lowest cost, it also has less effectiveness.[13]

The smart pumps infusion pump has software in which a drug library is installed. Connected to the Internet, this system runs scheduled and established applications, and promotes modes of analysis of the collected data. For each drug in the library, the following parameters can be set: dose unit, standard concentration, maximum and minimum doses, and infusion rates. There is the possibility of an infusion rate with relative and absolute limits ("soft limits" and "hard limits", respectively). When relative limits are violated, an alert is generated, but the infusion is allowed to continue. The alert of absolute limits, on the other hand, promotes the cancellation or reprogramming of the infusion.[14-15] It is currently one of the recommended technologies for greater safety in the administration of venous solutions.[15]

However, although smart pumps represent a major advance for intravenous therapy, alternative solutions may be performed by users to bypass the safety barrier (the alarms) of the device. Thus, it is essential the participation of the nursing team as a protagonist for the improvement of this technology, aiming a safer health care to the patient and the professional.[16]

Following the analysis of the selected articles and the scientific evidence found, we consider relevant the presentation of two themes: understanding the causes of alarm fatigue and the measures that can prevent alarm fatigue in infusion pumps.

It is also noteworthy, in the studies of this review, that the recorded alarms were analyzed through the data stored in the BI, directing improvements to its usability.

Understand the causes of infusion pump alarms

The context of the care practice allows us to understand why the alarms sound; and that the heterogeneity of the characteristics of the pediatric ICU patient, from infants to adolescents admitted, requires varying doses and time of drug infusion, making the settings of smart pumps challenging, relying on the participation of an interdisciplinary team for their adequacy.[17]

Among the causes of alarms that may contribute to the occurrence of alarm fatigue, we obtained:

1) Drug library incomplete to meet clinical practice.[18-19] Drug libraries should be specifically designed for each unit; the occurrence of excessive alarms due to attempts to insert a drug that is not inserted in the library makes nursing staff avoid using the safety software (drug library), increasing the risk of errors as they can manually program the infusions.

Studies have reported that one of the limitations of this technology is allowing programming of drugs that are not in the library; where failure to use the drug library in BI by nursing staff can lead to legal implications.[20,21] Opting for alternative solutions (manually inserting drugs) can put patient safety at risk.

However, the option of not using the drug library has advantages for certain scenarios, such as emergency situations that require rapid patient stabilization. In cases like these, searching for the drug in the database could result in wasted time.[22]

2) The absolute and relative limits per drug in the drug library are overly rigid.[18,22-24] These limits are intended to draw the user's attention to the possibility of errors in the dose or infusion rate programmed for the patient.

As for the type of alarms, a study reveals that 42.8% and 55.7% of the alarms are due to attempts to exceed the rigid and flexible drug limits, respectively. Many times, the numerical rounding that facilitates the handling of drugs by nursing staff and physicians causes unnecessary alarms.[25]

However, the usefulness of the relative limit has been questioned and ignored because it allows the infusion to continue without reprogramming.[26] It can be seen that 71.5% of relative alarms when triggered are ignored, compared to 28.5% of strict alarms that imply mandatory reprogramming of the infusion.[25]

3) Medication preparation and administration protocol not in accordance with that established in the drug library.[19,22,23] Preparation of venous infusions, when not centralized in the pharmacy service, are under the responsibility of the nursing team, which can lead to discrepancy with the standards established in the drug library of the BI and what is available in the service, making communication between physicians, nurses and pharmacists essential.

As for the type of drug that most contributes to the occurrence of alarms triggered in the BI, a study reveals that antibiotics are the ones that are most commonly used.[19] In addition to unnecessary alarms issued by the BI, the dose, infusion time or concentration error can be disastrous.

Nurses play an essential role in preventing medication errors that can cause harm to the child's health. They are responsible for planning the administration of administration of drug therapy, being characterized as the last barrier between the error and the patient.[15]

4) Vacation period.[25] The months corresponding to the vacation period demand the incorporation of substitute staff with less familiarity with the unit's equipment and protocols.

Studies highlight that between the months of January and February, June and December there was an increase in triggered alerts, as well as a greater number of substitute personnel, favoring the susceptibility to errors involving medications.[24,25]

Devices such as smart pumps need to be designed from the known limitations of human performance. Adherence to usability principles often results in intuitive devices that require little training, make errors difficult, and, if they occur, allow for immediate recognition and recovery.[24] Thus, it contributes to the interaction of novice staff with the infusion pump.

It is noticed that before the understanding of what leads to the occurrence of alarms, the implementation of human factors engineering (HFE) gains visibility in the health context.[26] This refers to the interaction of the human being with the technology inserted in his real work environment, aiming to improve the effectiveness, efficiency, and satisfaction of this interaction.[27] Scientific evidence reveals that little investment in HFE in the design and implementation of new technologies may result in low quality care, putting patient safety at risk; as well as undesirable outcomes for employees and the organization such as: job dissatisfaction, burnout syndrome, injuries, and high turnover.[26,28]

The Food and Drug Administration recorded 500 patient deaths related to alarms in five years; emphasizing the need for alarm management for patient safety.[29] Understanding the reason for alarms within a multifaceted context such as the pediatric ICU is considered a major advance in the relationship between man and technology, improving its usability.

Measures that can prevent alarm fatigue in infusion pumps

The reduction of clinical alarms has been a priority among health care institutions and industries.[7] The Joint Commission has approved the safety of clinical alarms as one of the goals for patient safety; requiring that health services identify the most important AMS alarms in order to be managed and used safely in health care.[30]

It is relevant to emphasize that alarm fatigue does not follow a cause and effect line related to an individual condition of the health care professional, but is the sum of several areas such as technology, infrastructure, workflow/process, and a sociotechnical system of people working in teams.[31]

The measures that can prevent alarm fatigue in infusion pumps presented in this review are not intended as a rule to be implemented, but as recommendations that can reduce unnecessary alarms:

1) Periodic review of the drug library (additions, corrections and exclusion of drugs), in addition to good communication with the nursing team.[18-19] Studies show a reduction of unnecessary alerts from 1.74% to 0.4% of the number of alerts, according to the number of infusions initiated through the drug library with this measure.[19]
2) Adjustment of absolute and relative limit alarms reconciled with clinical practice. Study reveals that violation of absolute maximum limits promoted the highest number of unnecessary alarms.[24] The established limits reduce medication errors by underdosing or overdosing during BI programming, of which 49% of the 92 errors intercepted were classified as errors of moderate to catastrophic severity for the patient.[20]
3) Developing guidelines for intravenous drug preparation as support for physicians and nurses that address: established standard concentrations, method of preparation, stability of the intravenous mixture, recommended minimum administration time, administration route, and events related to the administration process of each drug included in the drug library.[23,27]
4) Training: configured the strategy of high relevance for newcomers in any hospital unit.[18,22,25] Staff education must address not only the "how" to use BI, but the "why" of the importance of adherence to medication safety software, understanding that with this it is possible to increase its usability and reduce nuisance alarms.[6,31] In the intensive care setting, as alarms are reduced, the greater is the appreciation of those that alarm.

In care practice, we have observed alternative solutions in the operation of infusion pumps; these are defined as "informal practices that do not follow explicit or implicit rules, assumptions or intentions of the designers of a system. The use of a calculator can be exemplified as an alternative solution; one that can be provided through training.

Intelligent pumps can reduce, but not eliminate, errors in the administration of continuous infusions. These depend on the interaction with their users (nursing staff), environmental factors (noise and lighting), cultural habits (institutional routines), and organizational decisions (implementation, training, and decisions about the drug library)[17].

The use of BI safely requires nurses to monitor their practices, and be agents of change to adapt them according to their real work context. BI usability studies in pediatric intensive care enable its implementation for greater patient and professional safety in care practice. In this context, it is verified the relevance to the nurse's role in the adaptation needs of new technologies for venous infusions.

This study reveals the importance of equipment in the qualification of health care and patient safety, especially in pediatric intensive care units.

CONCLUSION

The causes of alarm fatigue involve low user interaction with the equipment, inadequate work processes and low investment in preventive measures for its occurrence. the safe use of infusion pumps requires a team to monitor their practices and act promoting changes in the work context. identify the causes of alarm fatigue in usability studies of pediatric intensive care infusion pumps

The scientific evidence on the causes of alarm fatigue in usability studies of pediatric intensive care infusion pumps showed the importance of understanding their causes in the care practice to then implement strategies for preventing alarm fatigue. It involves low user interaction with the equipment, inadequate work processes and low investment in preventive measures for its occurrence. Therefore, the participation of an interdisciplinary team (physicians, nurses and pharmacists) is necessary. The use of infusion pumps safely demands a team that monitors its practices and is an agent of change, according to its real work context.

As a limitation, there is a scarcity of national and international studies with volumetric BI in the pediatric clientele, still widely used in Brazil. Usability studies with volumetric BI are recommended in order to be closer to our care practices.

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Corresponding author
Elizandra Cassia da Silva Oliveira
Address: Estrada do Arraial, 2405, Tamarineira
Recife/PE, Brazil
Zip code: 52.051-380
Email address: elizandra.cassia@bol.com.br

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