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Review

The organizational and clinical impact of integrating bedside equipment to an information system: A systematic literature review of patient data management systems (PDMS)

Amy Cheung[a], *Floris H.P. van Velden*[a,b,*], *Vera Lagerburg*[a], *Niels Minderman*[c]

[a] *Department of Information, Communication and Medical Technology (ICMT), Catharina Hospital, PO Box 1350, 5602ZA Eindhoven, The Netherlands*

[b] *Department of Radiology & Nuclear Medicine, VU University Medical Center, PO Box 7057, 1007MB Amsterdam, The Netherlands*

[c] *Department of, Medical Spectrum Twente, PO Box 50000, 7500 KA, Enschede, The Netherlands*

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ABSTRACT

Objective: The introduction of an information system integrated to bedside equipment requires significant financial and resource investment; therefore understanding the potential impact is beneficial for decision-makers. However, no systematic literature reviews (SLRs) focus on this topic. This SLR aims to gather evidence on the impact of the aforementioned system, also known as a patient data management system (PDMS) on both organizational and clinical outcomes.

Materials and Methods: A literature search was performed using the databases Medline/PubMed and CINHAL for English articles published between January 2000 and December 2012. A quality assessment was performed on articles deemed relevant for the SLR.

Results: Eighteen articles were included in the SLR. Sixteen articles investigated the impact of a PDMS on the organizational outcomes, comprising descriptive, quantitative and qualitative studies. A PDMS was found to reduce the charting time, increase the time spent on direct patient care and reduce the occurrence of errors. Only two articles investigated the clinical impact of a PDMS. Both reported an improvement in clinical outcomes when a PDMS was integrated with a clinical decision support system (CDSS).

Conclusions: A PDMS has shown to offer many advantages in both the efficiency and the quality of care delivered to the patient. In addition, a PDMS integrated to a CDSS may improve clinical outcomes, although further studies are required for validation.

* Corresponding author at: Department of Radiology & Nuclear Medicine, VU University Medical Center, PO Box 7057, 1007MB Amsterdam, The Netherlands Tel.: +31 20 444 1541.
E-mail address: f.vvelden@vumc.nl (F.H.P. van Velden).

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Contents

1. Introduction

The proliferation of medical information in hospitals has resulted in a growing demand for information technology (IT) to effectively support the management of data. While IT has the potential to transform the delivery of healthcare, the introduction of such a system is a challenging task that has profound implications on the organization. A Clinical Information System (CIS) is an IT system that has been established in many hospitals today. It is a broad term used to describe a computer-based system capable of collecting, storing and/or manipulating clinical information important to the healthcare delivery process. Examples of currently available CIS's include the Electronic Health Record (EHR), Hospital Information System (HIS), Computer Physician Order Entry (CPOE) and Patient Data Management System (PDMS). The impact of an EHR [1–3] and CPOE [4–8] has been widely investigated in literature; however, PDMS's have received considerably less attention. Given that the purchase of a PDMS requires significant investment, not only financially but also from a resource perspective, an overview of the potential impact of introducing a PDMS can be beneficial for decision-makers.

Our definition of a PDMS is an information system that automatically retrieves data from bedside equipment (e.g. a patient monitor, ventilator, intravenous pump, etc.). The data are subsequently presented in a structured format that enables improved interpretation and manipulation of the data [9,10]. There has been tremendous development in the PDMS since it was first introduced in the late 1980's. The first generation PDMS was a standalone system that only provided automatic data collection and integration from limited bedside equipment. Over the years, the PDMS has grown in sophistication and expanded its functionality to beyond what it was originally conceived to offer and can now support not only automatic data collection and integration of various bedside equipment, but also data manipulation, statistical analysis and clinical decision support.

There have been previous systematic literature reviews investigating a CIS [11–13], in which the CIS is an information system that includes one or more of the aforementioned subgroups described; however, no systematic literature review has focused solely on the impact of a PDMS. Furthermore, the systematic literature reviews on a CIS concentrate primarily on the organizational impact (e.g. charting, documenting, patient care, etc.) and not on the clinical outcomes. The purpose of this systematic literature review is to gather evidence on the impact of integrating bedside equipment to an information system on both the organizational and clinical outcomes.

2. Methods

The Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) [14] was followed for this review.

2.1. *Search strategy*

A literature search was performed using the online databases Medline/PubMed and Cumulative Index to Nursing and Allied Health Literature (CINHAL) for peer-reviewed articles in the English language published between January 2000 and December 2012. The following search term was used to capture all the applicable departments in the hospital: *(patient data management system* OR clinical information system* OR ICU information system* OR computerized clinical documentation system* OR critical care information system* OR intensive care information system* OR anaesthesia information management system*) AND (implement* OR experience OR introduc* OR install*)*. Articles were included in the review if they satisfied the following criteria:

1. Description of a PDMS based on our definition
2. Evaluation of at least one of the following:
   a. Implementation experience
   b. Impact on workflow
   c. Attitudes towards a PDMS
   d. Clinical outcomes

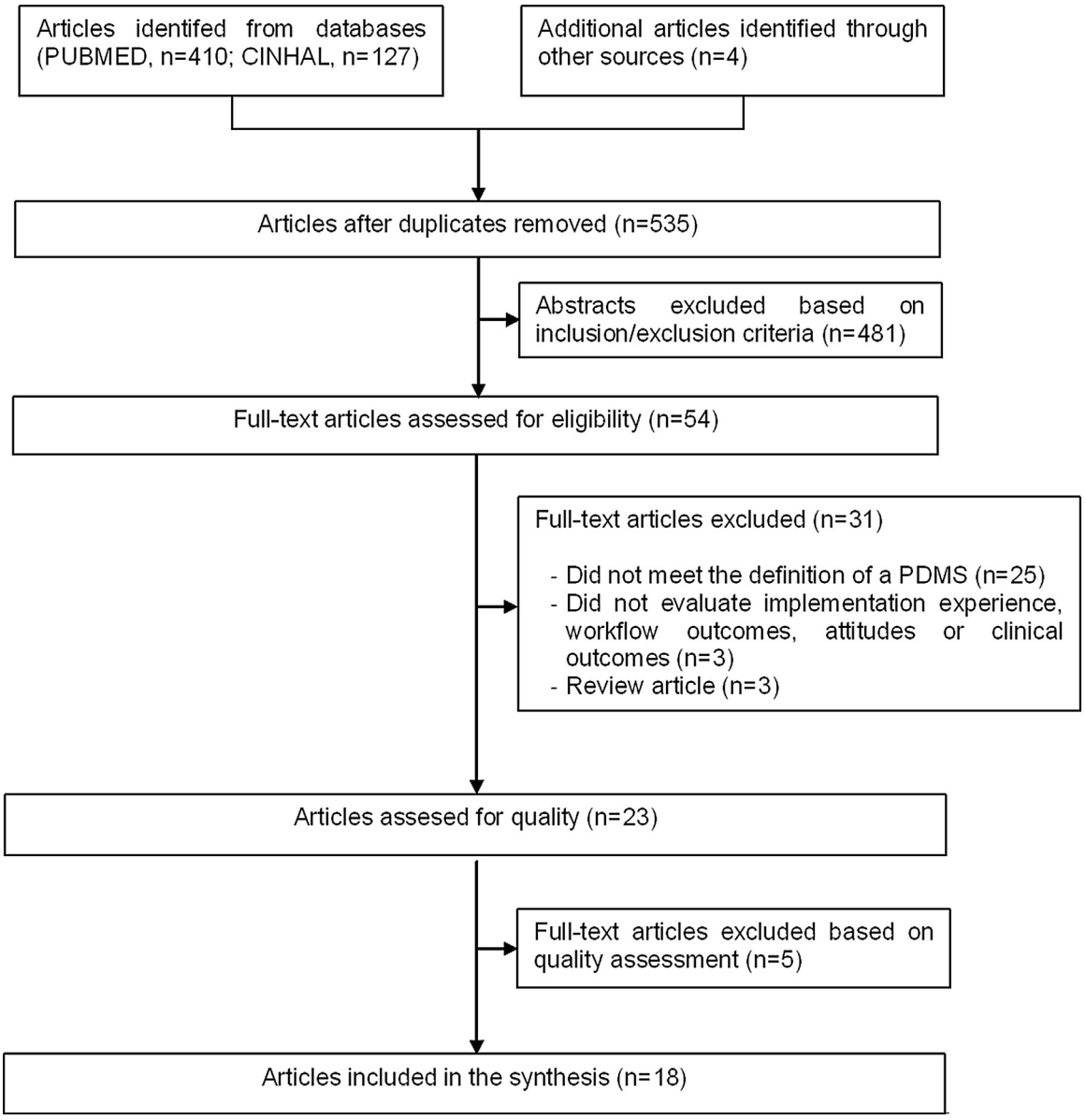

Fig. 1 – Study selection flow diagram.

Primary care related articles, congress abstracts, editorials and review articles were excluded.

2.2. *Study selection*

The first step of the study selection involved screening titles and abstracts based on the inclusion/exclusion criteria. When it was unclear from the title and abstract if a PDMS was described, the article was bypassed to the second step where the full text was analysed. Subsequently, the articles underwent a quality assessment, as recommended by the Cochrane Collaboration [15]. Two different quality assessment tools were used. Quantitative and qualitative articles were scored using a modified version of the quality assessment tool devised by the Effective Public Health Practice Project [16]. As no suitable quality assessment tool was available for the descriptive articles (e.g. a description of the implementation trajectory), the authors developed their own tool to assess these studies. The two assessment tools are available as supplementary material. The screening, quality assessment and data extraction of the articles were conducted independently by two reviewers (AC and FHPvV) and any disagreements were resolved by consensus.

3. Results

3.1. *Overall results*

The search of the databases returned 537 hits and after removing duplicates, 531 articles remained. An additional search conducted using Google and Google Scholar led to the retrieval of four further hits, resulting in 535 potentially relevant articles. After assessing the title and abstracts, 54 articles

Table 1 – Quality assessment ratings.

Publication	Quality assessment ratings Quantitative and qualitative studies	Descriptive studies
Ballermann et al. [23]	Moderate [a]	–
Ballermann et al. [24]	Strong	–
Benson et al. [25]	Moderate [b,c]	
Bosman et al. [26]	Strong	–
Bürkle et al. [17]	Weak [a,d]	–
De Mul et al. [27]	–	Strong
De Reus [18]	–	Weak [e,f,g,b,c]
Doulgas et al. [28]		Strong
Donati et al. [29]	Strong	Strong
Eden et al. [30]	Strong	Strong
Eden et al. [31]	Strong	
Ehrenfeld et al. [32]	Strong	
Eslami et al. [33]	Strong	–
Fraenkel et al. [34]	Strong	–
Fretschner et al. [22]	Weak [h,d]	Moderate [i,e,g,b]
Junger et al. [19]	Weak [h,d]	Weak [i,e,g,b,c]
Lipp and Williams [20]	–	Weak [i,f,g,b,c]
Menke et al. [21]	Weak [a,h]	–
Meyfroidt et al. [35]	Strong	–
Nelwan et al. [36]	–	Strong
Saarinen and Aho [37]	Strong	–
Van Vliet [38]	–	Moderate [i,e,f,c]
Wong et al. [39]	Strong	–

[a] Risk of selection bias.
[b] No information on testing.
[c] No information on the configuration of the PDMS.
[d] No statistical tests applied.
[e] No information on information systems connected to the PDMS.
[f] No information on time to go live.
[g] No information training given to users.
[h] Missing information on validity and reliability of data collection methods.
[i] No information on the equipment connected to the PDMS.

remained for the full text review. Following analysis of the full text articles, 23 articles were considered relevant for the systematic literature review. The flow diagram is depicted in Fig. 1.

In the quality assessment phase, five articles received a weak rating and were eliminated [17–21]. One article received a weak rating for the quantitative or qualitative component, but a moderate to strong rating for their descriptive component;

Table 2 – Study design.

Publication	Design	Organizational			Clinical
		Descriptive	Quantitative	Qualitative	Quantitative
Ballermann et al. [23]	Pre-post implementation		x		
Ballermann et al. [24]	Pre-post implementation		x		
Benson et al. [25]	–	x			
Bosman et al. [26]	Randomized controlled trial		x		
De Mul et al. [27]	–	x			
Donati et al. [29]	Observational	x	x	x	
Douglas et al. [28]	–	x			
Eden et al. [30]	Pre-post implementation	x	x	x	
Eden et al. [31]	Pre-post implementation		x		
Ehrenfel et al. [32]	Pre-post implementation		x		
Eslami et al. [33]	Pre-post implementation				x
Fraenkel et al. [34]	Pre-post implementation		x	x	
Fretschner et al. [22]	–	x			
Meyfroidt et al. [35]	Pre-post implementation				x
Nelwan et al. 2007 [36]	-	x			
Saarinen and Aho [37]	Pre-post implementation		x		
Van Vliet [38]	–	x			
Wong et al. [39]	Pre-post implementation		x		

Table 3 – Department, PDMS product, monitoring equipment and information systems details specified per article.

Publication	Country	Institution	Department	Product (Vendor)	Monitoring equipment						Information system			
					Patient monitor	Ventilator	Anaesthesia machine	IV[a] pump	Dialysis machine	Blood gas analyzer	LIS[b]	HIS[c]	Pathology	ADT system[d]
Ballermann et al. [23,24]	Canada	University of Alberta Strollery Children's Hospital	ICU[e] PICU[f]	No information available	x	x					x			
Benson et al. [25]	Germany	Justus-Liebig-University Giessen	ICU	NarkoData 3.3 (IMESO GmbH)	x		x					x		
Bosman et al. [26]	Netherlands	Onze Lieve Vrouwe Gasthuis	ICU	Quantitative Sentinel 5.5 (GE)	x	x		x				x		
De Mul et al. [27]	Netherlands	Erasmus MC	ICU	CareSuite 6.3 (PICIS)								x		
Douglas et al. [28]	U.S	Ochsner Clinic Foundation	OR[g]	DocuSys (Proprietary)	x		x				x	x		
Donati et al. [29]	Italy	University Hospital Ospedali Riuniti Umberto I–G.M. Lancisi–G.Salesi	ICU	Quantitative Sentinel (GE)	x	x		x		x	x	x		
Eden et al. [30,31]	Israel	Lady Davis Carmel Medical Center	OR	Metavision (iMDsoft)	Bedside equipment mentioned but not specified							x		
Ehrenfeld et al. [32]	U.S	–	–	No information available	x									
Eslami et al. [33]	Netherlands	Academic Medical Center Amsterdam	ICU	Metavision (iMDsoft)		x								
Fraenkel et al. [34]	Australia	Royal Brisbane Hospital	ICU	CareVue (Philips)	x	x							x	x
Fretschner et al. [22]	Germany	Tübingen MU	ICU	CareVue (HP)	No information available									
Meyfroidt et al. [35]	Belgium	Leuven University Hospital	ICU	Metavision (iMDsoft)							x			
Nelwan et al. [36]	Netherlands	Erasmus MC	ICU	Innovian (Dräger)	x									

Table 3 – (Continued)

Publication	Country	Institution	Depart-ment	Product (Vendor)	Monitoring equipment						Information system		
					Patient monitor	Ventilator	Anaesthesia machine	IV[a] pump	Dialysis machine	Blood gas analyzer	LIS[b]	HIS[c]	Patho-logy	ADT system[d]
Saarinen and Aho [37]	Finland	Seinäjoki Central Hospital	ICU	CareSuite 6.1 (Dräger)	x	x		x	x					
Van Vliet [38]	Netherlands	Academic Medical Center Amsterdam	ICU	Metavision (iMDsoft)	Bedside equipment mentioned but not specified									
Wong et al. [39]	U.S	Long Beach Vetrans Affairs Hospital	ICU	Metavision (iMDsoft)	x						x			x

[a] IV: Intravenous.
[b] LIS: Laboratory information system.
[c] HIS: Hospital information system.
[d] ADT: Admission, discharge and transfer.
[e] ICU: Intensive care unit.
[f] PICU: Pediatric intensive care unit.
[g] OR: Operating room.

hence only their descriptive information was included [22]. Consequently, 18 studies were included in the systematic literature review. The results of the quality assessment can be found in Table 1.

Sixteen articles investigated the organizational impact of a PDMS and two articles evaluated the clinical impact of a PDMS. An article may report more than one study. The studies investigating the organizational impact can be divided into descriptive articles ($n = 8$), quantitative ($n = 10$) and qualitative studies ($n = 3$) (Table 2). The quantitative and qualitative studies comprised of three different designs: pre-post implementation ($n = 10$), observational ($n = 1$) and randomized controlled trial ($n = 1$).

3.2. *Terminology*

Six articles opted for the term CIS (33%) [23,24,27,29,34,37] to describe an information system connected to bedside monitoring equipment, five articles (28%) [22,33,35,36,38] used the term PDMS, five articles used the term Anaesthesia Information Management System (AIMS, 28%) [25,28,30–32] and two articles used the term intensive care unit (ICU) information system (ICUIS, 11%) [26,39].

The ICU was the most common choice for the implementation of a PDMS (Table 3). The data intensive environment inherent to these departments was the most widely reported rationale for introducing a PDMS. Fourteen articles (78%) provided information on the type of monitoring equipment or information systems integrated to the PDMS (Table 3). The PDMS was most frequently interfaced with a patient monitor (79%), followed by a ventilator (39%).

3.3. *Organizational outcomes*

Eight articles described their experience during the implementation of a PDMS (Table 2) [22,25,27–30,36,38]. Examples of information provided included the implementation time (from purchase to go-live), configuration phase (e.g. selection of information to present and desired layout), description and duration of training given to the medical staff and key advantages and disadvantages of a PDMS experienced after implementation. Five articles reported the implementation time, which ranged from 11 months to 4 years. Five articles discussed the efforts required during the configuration phase, which often consisted of an analysis of the workflow and data collection processes [22,27,28,30,36]. The medical staff was involved during various iterations of the configuration, which lasted between 3 and 9 months. Seven articles discussed the training given, which varied from a 1 day to 1 week [25,27–30,36,38]. Doctors and nurses often received different training courses and extra training was given to super-users (first point of contact in the department when issues arise). The advantages and disadvantages encountered were described in four articles [22,28,36,38]. The advantages were diverse and included improved accuracy, legibility, data accessibility and decision support. The only disadvantage reported was difficulty with data retrieval.

Ten articles investigated the impact of a PDMS on the organizational outcomes, measured using both quantitative and qualitative methods (Table 4) [23,24,26,29–32,34,37,39].

Although each study assessed different outcomes, an attempt was made to cluster comparable outcomes together. There were seven groups identified: charting, documenting, direct patient care, workflow, errors and incidents, resources and overall satisfaction.

Charting: Three studies evaluated the impact of a PDMS on charting data. One study found the documentation in the registration phase to be 29 min less in the group using a PDMS compared to the group using paper records [26]. Another study demonstrated a reduction of 34 min in the recording time of vital signs, therapeutic orders and computing fluid balance and scores compared to a paper record [29]. A third study observed a 3 min decrease in the time spent taking vital signs [39], although the result was not statistically significant. The same study also showed that the number of occurrences in performing the charting task reduced after implementation of a PDMS. All studies cited a high level of interfacing with bedside equipment for the time saving, as the PDMS eliminated the need to enter data manually.

Documenting: Three studies assessed the impact of a PDMS on documenting. One study demonstrated a statistically significant decrease in the percentage of time spent on documentation, in addition to a reduction in the occurrence of documenting [39]. Two explanations were given for the improvement. First, the hospital had an EHR capable of exchanging information with the PDMS; hence patient information was automatically available. Second, there has been an increase in topics that nurses are required to document and a PDMS is very useful in managing large amounts of information. Another study reported an increase in documenting time, but the results were not statistically significant [37]. The qualitative study showed a significant increase in the perception that a PDMS resulted in less than 10 min spent on documentation and led to less time spent on documentation overall [34].

Direct patient care: Five studies investigated the impact of a PDMS on direct care. One study observed an increase of 29 min spent on patient care [26]. Another study demonstrated a 42 min increase in time spent on patient care [39]. In the same study, the occurrence of direct patient care also reduced. A third study showed a statistically significant increase in the time available for the care of an ICU and intensive care nursing. [37]. All three studies suggest the extra time available for direct patient care resulted from time savings in other ICU activities, e.g. charting and documenting. One qualitative study indicated that staff were partly concerned about the decrease in attention to patients before go-live, although staff did not believe this to be true 3 months after implementation [30]. A second qualitative study showed that the respondents perceived an increase in time available for patient care [34].

Workflow: Two studies reported the impact of a PDMS on the workflow. One study demonstrated that the care provider still referred to paper records significantly more often than the PDMS during verbal report 12 months after implementation [24]. A plausible explanation for the result is that a "hybrid" environment was in place, i.e. the relevant information was distributed between the paper records and the PDMS. As no single source of information existed, both the paper records and the PDMS were consulted. However, it is likely that clinicians preferred using paper records for information aggregation. Another study by the same author investigated the impact of a PDMS on the frequency of interruptions (an external factor, e.g. an alarm, another care provider or a patient, that causes the observed care provider to cease their task) [23]. The study showed that physicians experienced significantly less frequent interruptions per hour after the implementation of a PDMS, while nurses were interrupted more often. The disparity in results is explained by the different strategies undertaken by the physicians and nurses when utilizing a PDMS. Physicians tended to perform their documentation tasks at a distant location from the patient and deferred communications to a later time. However, nurses are required to spend large proportions of their time close to the patient and thus were limited in their attention for the PDMS.

Errors/incidents: Four studies evaluated the impact of a PDMS on a range of errors and incidents. In one study a statistically significant decrease in the number of medication incidents, intravenous incidents and ventilation incidents was reported. The PDMS facilitated legible data, consistent information and terminology, standardized formatting and adequate security, all of which were reported to be effective in reducing incidents. There was however a rise in "other incidents" [34]. These are incidents that do not fall under any of the previous categories, although the article does not provide any further details. Another study investigated the rate of alarm reactivation following the separation from a cardiopulmonary bypass monitor [31]. Alarms are deliberately disabled during cardiac surgery; however, often the alarm is not reactivated, which poses a safety issue for the patient. The introduction of an automatic reminder significantly increased the rate of alarm reactivation. It was reported that the addition of an educational meeting was required to achieve compliance. A third study [32] assessed the impact of automatic notifications on the documentation of blood pressure (BP) data. Basic anesthetic monitoring requires that the BP should be measured at least every 5 min. However, disruptions in the continual monitoring of BP often occur. An automatic notification system reduced the incidence of cases with at least one occurrence of 10 min gap of BP data in hospital A. However, in hospital B, the incidence only decreased if a notification was provided when a 6 min gap occurred. Finally, a qualitative investigation by one study revealed that 88% of the medical staff, 87% of the nursing staff and 100% of the consultants considered the PDMS to reduce transcription errors [29].

Resources: Only one study assessed the impact of a PDMS on nursing resources [34]. An increase in nursing recruitment and retention of nursing staff after the implementation of a PDMS was reported, although *no* statistical analysis was performed.

Overall satisfaction: Two studies investigated qualitatively the overall satisfaction of using a PDMS. One study showed a positive perception of time saved compared to the paper record (medical staff 96%, nursing staff 100%, consultants 80%) and in general (medical staff 80%, nursing staff 83%, consultants 76%) [29]. In addition, almost all the medical staff did not want to return to paper-based recording (medical staff 100%, nursing staff 100% and consultants 96%). Another study indicated that staff were partly concerned about an increased workload before go-live of a PDMS, although staff did not believe this to be true 3 months after implementation [30].

Table 4 – Studies assessing the organizational and clinical impact of a PDMS.

Publication	Data	Outcome	Significance
Charting			
Bosman et al. [26]	Quantitative	↓ Time (−29 min)	$p < 0.001$
Donati et al. [29]	Quantitative	↓ Time (−34 min)	$p < 0.001$
Wong et al. [39]	Quantitative	↓ Time (−3 min)	NS[a]
		↓ Occurrences (taking vital signs) (−0.7/hr)	$p < 0.001$
Documenting			
Fraenkel et al. [34]	Qualitative	Less time spent documenting	$p < 0.05$
Wong et al. [39]	Quantitative	↓ Time (−52 min)	$p = 0.025$
		↓ Occurrences (documenting) (−5.3/hr)	$p < 0.001$
Saarinen and Aho [37]	Quantitative	↑ Time (15 min)	NS
Direct patient care			
Bosman et al. [26]	Quantitative	↑ Time spent on direct patient care (+29 min)	95% CI[b]
Eden et al. [30]	Qualitative	Unconcerned about decrease in attention to patients	$p < 0.001$
Fraenkel et al. [34]	Qualitative	Increase in time available for patient care	$p < 0.001$
Wong et al. [39]	Quantitative	↑ Time spent on direct patient care (+42 min)	$p = 0.085$
		↓ Occurrences in direct patient care (−2.1/hr)	$p = 0.02$
Saarinen and Aho [37]	Quantitative	↑ Time spent on care of ICU patient (21 min)	$p < 0.05$
		↑ Time spent on care intensive care nursing (14 min)	$p < 0.05$
Interruptions			
Ballermann et al. [23]	Quantitative	↓ Interruptions experienced by physicians (−1.85/hr)	$p < 0.05$
		↑ Interruptions experienced by nurses (+4.3/hr)	$p < 0.05$
Ballermann et al. [24]	Quantitative	Referral to paper records > Referral to PDMS	$p < 0.05$
Errors and incidents			
Eden et al. [31]	Quantitative	↑ Alarm reactivation	$p < 0.001$
Ehrenfeld et al. [32]	Quantitative	↓ Incidents with at least 1 blood pressure gap	$p < 0.0001$
Fraenkel et al. [34]	Quantitative	↓ Medication errors (−30 errors)	$p < 0.05$
		↓ Intravenous incidents (−94 incidents)	$p < 0.001$
		↓ Ventilation incidents (−41 incidents)	$p < 0.05$
		↑ Other incidents (+122 incidents)	$p < 0.001$
Donati et al. [29]	Qualitative	Reduced transcription errors	–
Resources			
Fraenkel et al. [34]	Quantitative	↓ Staff turnover (−10/year)	–
Overall satisfaction			
Donati et al. [29]	Qualitative	Time saved in general	–
		Did not want to return to a paper-based system	–
Eden et al. [30]	Qualitative	Unconcerned about increase in workload	$p = 0.001$
Clinical outcome			
Eslami et al. [33]	Quantitative	↑ Mean excessive tidal volume in normal mode	$p = 0.01$
		↓ Mean excessive tidal volume in spontaneous mode	$p = 0.03$
Meyfroidt et al. [35]	Quantitative	↓ Blood glucose	$p = 0.002$
		↓ Hyperglycemic index	$p = 0.004$
		↓ Patients with hypoglycemia	$p = 0.043$

[a] NS: non significant.
[b] CI: confidence interval.

3.4. *Clinical outcomes*

Two articles reported clinical outcome measures, both of which involved a clinical decision support system (CDSS) integrated to a PDMS (Table 4). One study showed that the use of a pop-up window displaying the recommended tidal volume (V_T) increased the adherence to a local guideline to optimize V_T in ICU patients. This was observed in mechanically ventilated for longer than 24 h in normal and spontaneous mode [33]. A lower V_T is important to improve survival in mechanically ventilated patients with acute lung injury. Another study demonstrated that an electronic alert that appeared at specific blood glucose (BG) thresholds reduced the mean BG per patient, hyperglycemic index and glycemic penalty index. Additionally, fewer patients had hypoglycemia [35]. Although the reduction in mean BG per patient was significant, it was small and had no impact on the patient outcome.

4. Discussion

At present, there is no consensus on the use of terminology for an information system capable of integrating to bedside equipment. The term CIS is probably the most suitable term given that hospitals are converging to a single information system fully integrated across departments, which comprises both the essential components of an EHR and the integration to bedside equipment. The ICU is the most common setting for

the integration of bedside equipment to an information system, mainly driven by the large number of bedside equipment present in the ICU. However, it is predicted that the integration of bedside equipment will not be restricted to the ICU due to the growing use of bedside equipment in other departments, such as the operating room and emergency room.

When describing the implementation of a PDMS, it is important to provide sufficient and relevant information relating to the implementation process. Pertinent details include PDMS technical details, implementation time, configuration efforts, testing, training and advantages and disadvantages encountered. Information related to the integration of bedside equipment to the PDMS is also useful to report, especially since interoperability is a known issue.

The evolution of the PDMS in the last 20 years has resulted in improved functionality, such as statistical analysis, clinical decision support, order management, etc. Early PDMS were relatively basic in comparison, focusing primarily on automatic data collection; thus only studies from 2000 onwards were included in the SLR to ensure that the studies were sufficiently comparable. In the quantitative and qualitative articles, a wide range of outcome variables were investigated. The results indicated that the implementation of a PDMS led to a decrease in the time required for charting [26,29] and a decrease in the incidence of charting events [39]. This is an expected result given that automatic collection of data from beside equipment is more efficient than manual collection of data. Although data validation is required to be performed during automatic data collection, it is still less time consuming that entering data manually. The effect of a PDMS on documenting was mixed [34,37,39]. It is likely that the impact of a PDMS on documenting is related to how the computerized documentation is configured. A user-interface with standardized formats and optimized according to the patient and work processes will facilitate documentation and thus possibly save time as opposed to paper-based documentation. [34,37,39] However, if the user-interface is poorly organized and cumbersome to use, an increased amount of time will be required for documentation. A PDMS was demonstrated to have a positive influence on direct patient care [26,30,34,37,39]. The increase in direct patient contact is likely to be a consequence of the reduction in time spent on data collection, and in some cases, documentation, leading to more time available for the care of the patient. The impact of a PDMS was also affected by variations in the workflow. The number of interruptions was dependent upon the role of the medical professional as physicians experienced fewer interruptions after the implementation of a PDMS than nurses [23]. It is therefore important to perform an in-depth analysis of workflow impact when implementing a PDMS to understand how each user will be affected. A PDMS was reported to reduce the medication errors and intravenous and ventilation incidents following the implementation of a PDMS [29,31,32,34]. This can be explained by the increase in legilibity of text, in addition to the clear and orderly presentation of information offered by a PDMS. Fraenkel el al [34] was the only study to investigate the impact of a PDMS on resources. Although no statistical analysis was performed, it is worthwhile to mention that they reported a reduction of staff turnover rate from 20 to 10 staff per annum, which translated to a cost saving of 50,000 to 100,000 USD per annum.

The introduction of a new information system is a daunting prospect for the users as it often demands a new working approach and often without immediate and apparent benefits. Acceptance of users is crucial to the success of a new information system, therefore gauging the attitudes of the users towards a PDMS is vital to understanding how to ensure that it will be well accepted. Two studies that explored the overall perceptions of the users concerning a PDMS [29,30] provided encouraging results. The PDMS was shown to be well accepted and the majority did not want to return to a paper-based system once they had spent a few months using the system. It is clear that users need to experience the added value of a new information system before they are willing to accept it.

The clinical impact of a PDMS was investigated by only two studies [33,35]. The scarce literature available may be explained by the fact that a PDMS primarliy aims at improving the quality of the workflow of the frontline staff. This has an indirect effect on the patient care, and is thus more difficult to measure. The two studies that reported the impact of a PDMS on clinical outcomes both employed a PDMS with CDSS [33,35], suggesting that clinical decision support, which is more focused on the patient rather than the workflow, is required for any meaningful assessment of the impact on clinical outcomes. Both studies demonstrated a statistically significant improvement in outcomes after the implementation of a PDMS with CDSS, although the changes were small. Due to the limited studies, further research should be conducted to consolidate these findings. It is also important to note that Meydroit et al. [35] mentioned the possiblity of using an alternative computer system for providing the clinical decision support, but the abilty of a PDMS to combine physiological data, laboratory results, etc. offers many advantages. The concept of integrating a CDSS with a PDMS further reinforces the choice of CIS as the preferred teminology due the broad functionality it can offer.

An important message to be derived from the results is that a PDMS potentially offers more than just a replacement of a paper-based charting and documentation system, as considerable time savings can be achieved, leading to more time for direct patient care. In addition, improved legibility, consistency and structure of information can result in fewer errors. It is also important to recognize that the workflow should be optimized to integrate the PDMS in the monitoring, treatment and reporting of the patient condition in order to reduce unnecessary tasks and interruptions, which could diminish the added value of a PDMS.

Our study has some limitations. Not all relevant studies may have been captured as only English language articles were included in the search. In addition, a strict definiton of a PDMS was used during the search strategy, thus studies that did not use the term PDMS, CIS, ICUIS, AIMS, computerized clinical documentation system or critical care information system in their article, or any of the keywords such as implement*, experience*, introduc* or install* may have been missed. Furthermore, there is significant heterogentiy in the studies due to different settings and outcomes variables measured. Hence, there are a limited amount of studies that have investigated each outcome variable, making it difficult to draw concrete conclusions.

Summary points.
What was already known on the topic

- A PDMS automatically gathers and stores vital parameters from bedside equipment and presents the information in a structured form.
- A PDMS offers many advantages such as legibility, accuracy, accessibility, data analysis and data archiving.

What this study added to our knowledge

- There are few articles that provide sufficient information describing the implementation process.
- A PDMS was found to reduce the charting time, increase the time spent on direct patient care and reduce the occurrence of errors.
- The workflow should be optimized to integrate the PDMS in the patient care process to reduce unnecessary tasks and interruptions.

5. Conclusion

The authors believe that this is the first systematic literature review to investigate the impact of a PDMS on the organizational and clinical outcomes. A PDMS was found to reduce the time required for charting, increase the time for direct patient care and lead to fewer errors. The optimization of the workflow to integrate the PDMS is crucial to ensure that the added value of a PDMS can be fully exploited. Finally, a PDMS that is integrated to a CDSS has the potiential to improve clinical outcomes but further studies are required for validation.

Author Contributions

Study conception and design: Cheung, Van Velden
Acquisition of data: Cheung, Van Velden
Analysis and interpretation of data: Cheung, Van Velden
Drafting of manuscript: Cheung
Critical revision: Cheung,Van Velden, Lagerburg, Minderman

Competing interests

None.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ijmedinf.2014.12.002.

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