Mobile Clinical Decision Support Systems – A Systematic Review

Full Paper

Rahul Dwivedi
University of Texas, Arlington
rahul.dwivedi@mavs.uta.edu

Fereshteh Ghahramani
University of Texas, Arlington
fereshteh.ghahramani@mavs.uta.edu

RadhaKanta Mahapatra
University of Texas, Arlington
mahapatra@uta.edu

Abstract

In this review article, we provide a descriptive analysis of the current state of mobile decision support systems in the healthcare domain based on studies published in the following databases: Business Source Complete, CINAHL, Cochrane library, MEDLINE, PsycINFO, PubMed, ScienceDirect and Web of Science databases. A total of 29 studies were identified and analyzed to understand the current state of development, evaluation efforts, usability and challenges to adoption by patients and care providers. Our aim is to evaluate these systems and identify the key challenges which hinders their widespread adoption. Although, mobile based decision support systems in healthcare context have the potential to improve clinical decision making, the current state with low adoption rate and early stage of development need to be addressed for successful health outcomes.

Keywords

mHealth, mobile clinical decision support system, systematic review.

Introduction

In the past decade, policy makers and government agencies have called for increasing use of technology in the health care domain, including technologies such as mobile based clinical decision support systems and mobile apps. The use of mobile technology in the healthcare domain is referred to as mobile-health or mHealth and is defined as medical and public health practice supported by mobile devices, such as mobile phones, patient monitoring devices, personal digital assistants (PDAs), and other wireless devices (Bakken et al., 2014).

Decision support systems are interactive computer-based systems to help decision makers use data and models to solve unstructured problems,(Sprague Jr & Carlson, 1982). Traditionally the aim of decision support systems was not to replace the decision makers but to assist them in making decisions in difficult situations involving unstructured or non-routine problems. Computerized clinical decision support systems (CDSSs) are information systems designed to improve clinical decision making (Garg & Adhikari, 2005). Such decision making is often based on strong scientific evidence and research on treatment procedures, often known as evidence based medicine or evidence based treatment. Thus, the aim of CDSS is to present the scientific knowledge and evidence behind the treatment procedure and enable the health care provider to make decisions regarding patient care. Clinical decision support systems are software designed to be a direct aid to clinical decision-making. They match the characteristics of an individual patient with data in a computerized clinical knowledge base and then present patient-specific assessments or recommendations to the clinician or the patient for decision making (Sim et al., 2001). Well designed and implemented CDSS offer many useful decision making features to health care providers, such as, alerts involving medication procedure, suggestions for treatment plans, and reminders for overdue medical tasks. CDSS can provide clinicians, staff, patients

and other individuals with knowledge and person-specific information, intelligently filtered and presented at appropriate times, to enhance health and health care delivery.

One challenge faced by health care providers today is the lack of access to proper and consistent medical and/or patient information at the point of care. Mobile based clinical decision support systems can help in such scenarios by making clinical data and decision support tools available to the care provider in a timely manner and in varying health care settings (Dunsmuir et al., 2014). Thus, portability is a distinguishing feature of such systems. This advantage of mobile based CDSS become even more crucial in resource limited and remote settings.

The aim of this review is to gain insight into the current state of mobile based clinical decision support systems based on published research. Specifically, we address the following research questions in this study:

- What is the current state of maturity of mobile CDSS?
- How effective are these systems in improving clinical outcomes?
- What are the challenges and practical issues faced by users of these systems?

Literature Review

Systematic reviews are aimed at identifying, evaluating and summarizing findings on a research topic or a question based on some fixed criteria (Oxman et al., 1994). They differ from tradition reviews by adopting a replicable, scientific and transparent procedure aimed at minimizing biases through extensive literature search of previously published studies (Tranfield, Denyer, & Smart, 2003). Systematic reviews have become increasingly important in the health care domain and are of utmost interest to health care practitioners, researchers and clinicians to remain up to date with their field. Also, such reviews along with meta analyses serves as a breeding ground for advancing future research. Along with meta-analysis studies such reviews act as breeding ground for advancing further research. Systematic reviews are needed to efficiently integrate existing information and to establish whether scientific findings are consistent so as to be generalized among populations, settings and treatment variations (Mulrow, 1994). As per (Moher et al., 2009), "the value of systematic review depends on what was done, what was found and the clarity of reporting".

Within the healthcare domain, systematic reviews have been carried out for evaluating health care interventions (Liberati et al., 2009), evaluating diagnostic and screening tests for diseases (Deeks, 2001), on impact of health IT on quality, efficiency and costs of medical care (Chaudhry et al., 2006), on the relationship between clinical experience and quality of health care (Choudhry, Fletcher, & Soumerai, 2005) and on involving patients in planning and development of healthcare (Crawford et al., 2002) among various others. (Martínez-Pérez et al., 2014) carries out a literature and commercial review of mobile clinical decision support systems and applications. Our review is different from their work in many ways: they carried out a review of commercial apps while we didn't do so; they used only three search terms i.e. mobile AND clinical AND decision AND support for their literature review on only four academic databases while our search criteria is more comprehensive; and finally, their results concentrate more on to the commercial review of apps rather than on academic literature, which is the focus of our review.

Methodology

We obtained relevant articles published in the following databases: Business Source Complete, CINAHL, Cochrane library, MEDLINE, PsycINFO, PubMed, ScienceDirect and Web of Science. The search was conducted in April 2016 using the following keywords: m-health, mhealth, mobile health, decision support, decision support system, DSS, feedback, reminder, alert, expert system, evidence-based medicine, evidence based medicine. The initial query resulted in 789 articles. Figure 1 presents the flow chart that summarizes the article selection process.

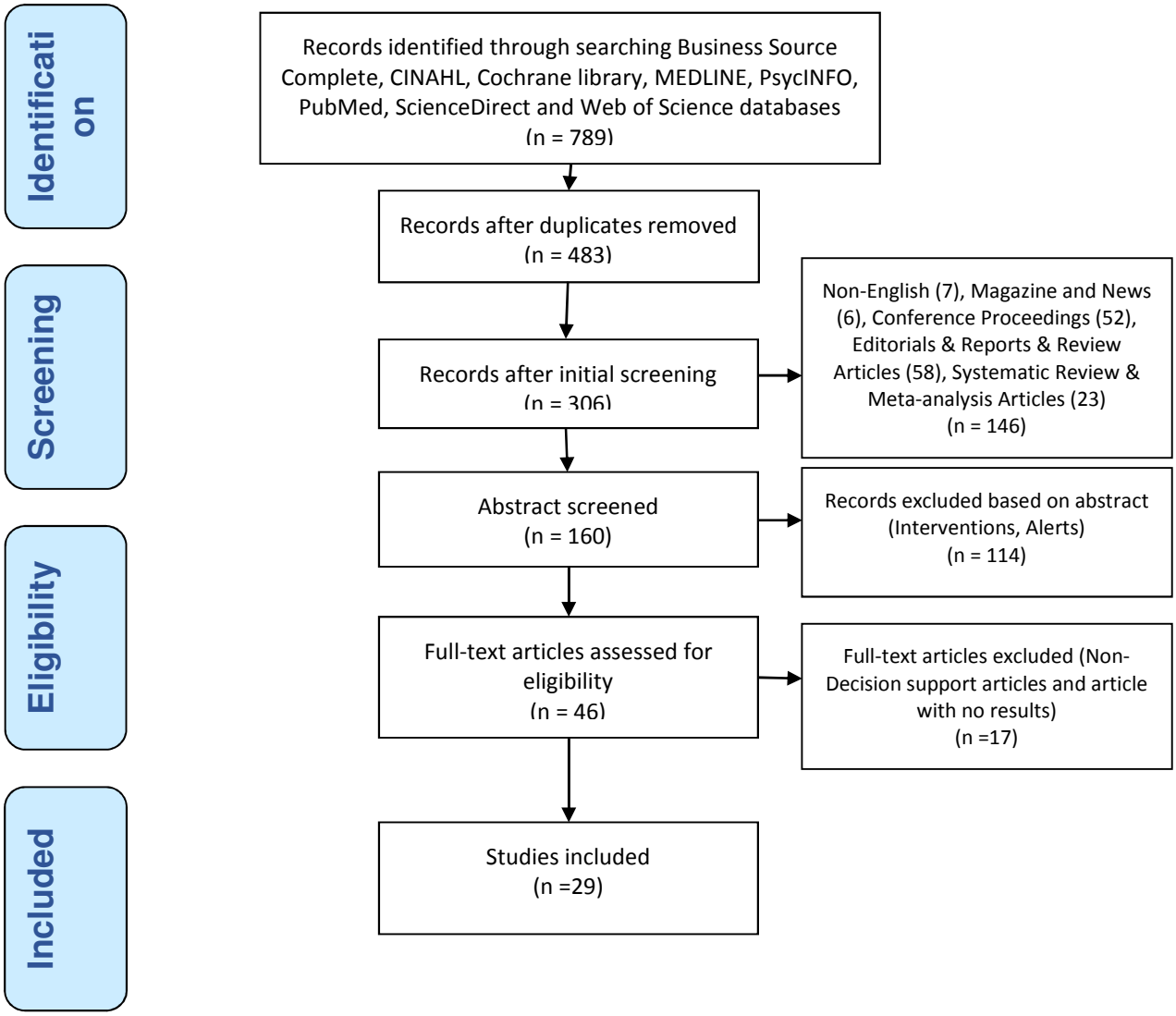

Figure 1 Flowchart representing process of identifying relevant articles

Results

Study Characteristics

The 29 articles in our study were published between 2005 and 2016 with most articles published during the years 2010 to 2016. The authors of these articles employed a multiplicity of research methods, including, field experiment, lab experiment, survey and focus groups. 9 of the publications that covered design, development and/or evaluation of a system didn't involve use of human subject (Han, Lee, & Park, 2010; Heslop, Weeding, Dawson, Fisher, & Howard, 2010; Lin, Shao, Zhang, & Fang, 2013; Michalowski & Ph, 2005; Minutolo, Esposito, & Pietro, 2015; Obermeier et al., 2016; Sadasivam & Gathibandhe, 2012; Santos et al., 2016; Varshney, 2014). The remaining 20 used human subjects in a field or lab setting. Of these 20 studies, 8 employed mixed method research methodologies with experiment (in lab setting or remote field setting) followed by survey questionnaire and interview or focus group discussion (Braun et al., 2016; Knoble & Bhusal, 2015; Lim, Cloete, Dunsmuir, Payne, & Scheffer, 2015; Madon, Amaguru, Malecela, & Michael, 2014; Olivia, Okyere, Kanter, & Bakken, 2014; Palazuelos, Diallo, Palazuelos, Carlile, & Jonathan, 2013; Praveen, Patel, Raghu, Clifford, & Pallab, 2014; Rabbi et al., 2015). One study involved a field experiment followed by survey questionnaire for evaluating usability of the system (Raghu, Praveen, Peiris, Tarassenko, & Clifford, 2015). Another used think aloud exercise with semi-structured

interviews and focus group discussions for evaluating usability and feasibility of a decision support tool (Vedanthan et al., 2015).

The articles revealed the use of mobile CDSS aimed at curing, managing and/or predicting the risks of both chronic as well as acute diseases and/or conditions. The chronic diseases or conditions addressed include cardiovascular diseases (Fayn & Rubel, 2010; Minutolo et al., 2015; Praveen et al., 2014; Raghu et al., 2015; Sannino & Pietro, 2014; Santos et al., 2016; Tseng & Wu, 2014; Zhang, Thurow, & Stoll, 2016), cancer (Bruin et al., 2015), tropical diseases (Madon, Amaguru, et al., 2014), hypertension (Vedanthan et al., 2015; Wannenburg & Malekian, 2015), obesity (Bakken et al., 2014), stress management (Han et al., 2010), pre-natal care (Olivia et al., 2014), smoking cessation (Hyun, Sookyunk Nirenberg, Anita Staats, Jo Anne Bakken, 2013), HIV / Aids (Sadasivam & Gathibandhe, 2012) and management of tobacco use (Cato, Hyun, & Bakken, 2014). On the other hand, acute diseases addressed in the articles are acute scrotum or scrotal pain in male adolescents (Michalowski, Farion, Pike, & Rubin, 2005), pre-eclampsia (Dunsmuir et al., 2014; Lim et al., 2015) and infectious / inflammatory diseases of the central nervous system in adolescents (Obermeier et al., 2016).

A word cloud of frequently occurring words is shown in figure 2, where the size of the word reflects its frequency of occurrence. As can be seen, mobile, health, system, data, use, clinical, care, mHealth, support and patient are some of the most frequently occurring words.

Figure 2 Frequently occurring words in articles under review

The preponderance of words such as proposed, testing, usability, designed and evaluation suggest that design, development and evaluation of mHealth decision support systems is a focal topic of discussion in many articles, thus indicating that many such systems are in their early stages of development. Similarly, terms such as errors and risk in the word cloud signify the importance of risk management and error reduction as topics of research in mobile CDSS.

Participants

The age of participants ranged from 2 years for obesity (Bakken et al., 2014) to 77 years for cancer (Bruin et al., 2015). 20 out of the 29 studies involved human subjects, who fall into three groups: patients, healthcare providers (nurses, nurse practitioners, and doctors) and community healthcare workers (CHW). Figure 3 shows the frequency of publication by subject type, where n represents the publication count for the specific group.

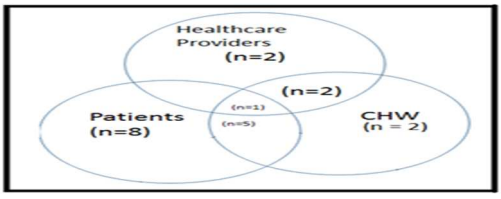

Figure 3 Publication frequency by user groups

The studies using only patient subjects are (Bakken et al., 2014; Bruin et al., 2015; Cato et al., 2014; Fayn & Rubel, 2010; Rabbi et al., 2015; Sannino & Pietro, 2014; Tseng & Wu, 2014; Wannenburg & Malekian, 2015). 5 studies use both patient and community health workers as participants (Braun et al., 2016; Knoble & Bhusal, 2015; Madon, Amaguru, et al., 2014; Olivia et al., 2014; Raghu et al., 2015). 1 study use doctors, community health workers and patients (Praveen et al., 2014), while 2 studies use only nurse participants (Hyun, Sookyunk Nirenberg, Anita Staats, Jo Anne Bakken, 2013; Vedanthan et al., 2015)

and 2 studies uses both nurse and community healthcare workers as participants (Dunsmuir et al., 2014; Lim et al., 2015). Finally 1 study uses volunteer for carrying out lab experiment (Zhang et al., 2016). Thus, nurses and community health workers have an important role to play in adoption and evaluation of these systems.

Surprisingly, none of the studies in our review targeted practitioners as the sole participants. This lack of involvement of practitioners needs further investigation. Furthermore, a preponderance of systems targeted at the patient as the end user suggests that we are moving towards a patient centered decision model.

Training community health workers or nurses on how to use mHealth decision support tool is mentioned in 3 studies (Palazuelos et al., 2013; Raghu et al., 2015; Vedanthan et al., 2015) while 1 study involved imparting training to both community health workers as well as physicians (Praveen et al., 2014). The duration of training varies from a minimum of 1 day to several weeks. 2 studies stress the importance of training after participants found it difficult to use the system (Madon, Olanya, Ntuli, & Michael, 2014; Olivia et al., 2014). Similarly (Braun et al., 2016) emphasizes training as a key for system success. Thus, training is a necessary component for successful adoption and continued usage of mobile CDSS, especially in cases where the user has no prior interaction with mobile technology.

Applications and platforms

Based on the type of applications, the systems fall into three categories: (1) decision support systems (Bruin et al., 2015; Minutolo et al., 2015; Modre-osprian, Pölzl, & Heidt, 2014; Palazuelos et al., 2013; Vedanthan et al., 2015; Zhang et al., 2016), (2) recommender systems (Palazuelos et al., 2013; Sadasivam & Gathibandhe, 2012), and (3) screening and diagnosis systems (Cato et al., 2014; Han et al., 2010; Hyun, Sookyunk Nirenberg, Anita Staats, Jo Anne Bakken, 2013; Knoble & Bhusal, 2015; Praveen et al., 2014).

The three-dominant mobile application development platforms, namely, Android, iOS, and Windows CE, were represented, although not equally, among studies. Android is the most popular choice among researchers in these studies. 2 studies used both Android and iOS platforms (Lim et al., 2015; Santos et al., 2016), whereas 1 study developed a client app for Windows CE platform (Han et al., 2010). Intelligent personal assistant for remote health care was implemented in 2 studies (Fayn & Rubel, 2010; Santos et al., 2016). Personalized health is the main topic of interest in 1 study (Fayn & Rubel, 2010). Context awareness and remote health monitoring with multiple sensors or body sensor network were main topics of interest in seven studies (Han et al., 2010; Minutolo et al., 2015; Rabbi et al., 2015; Sannino & Pietro, 2014; Santos et al., 2016; Wannenburg & Malekian, 2015; Zhang et al., 2016).

A multitude of underlying technologies were used to support decision support capabilities. Rule based design was the basis of decision support in a majority of studies (Fayn & Rubel, 2010; Michalowski et al., 2005; Minutolo et al., 2015; Praveen et al., 2014; Sadasivam & Gathibandhe, 2012; Sannino & Pietro, 2014; Zhang et al., 2016) whereas tree based,(Dunsmuir et al., 2014) and artificial neural network (Fayn & Rubel, 2010) based decision support systems were used in 1 study each. Cloud based servers, web services and web ontology language (OWL) were also used as development techniques in 3 studies (Lin et al., 2013; Santos et al., 2016; Tseng & Wu, 2014). 2 studies were based on simple mobile based textual tools with no active Internet access but involved data synchronization between the remote mobile client and server depending on network connectivity (Braun et al., 2016; Palazuelos et al., 2013).

Current state of maturity

Many articles under review aimed at evaluating the system either in a controlled lab environment or field setting using outcome parameters such as performance, accuracy, usability, efficacy, effectiveness and feasibility. One study carried out tests for verification of quality of physiological signals acquired by the proposed mobile application from physiological sensors, online activity recognition and alarm reliability of developed system, reliability of short-distance wireless communication, and reliability of remote wireless communication (Zhang et al., 2016). Another study based on body sensor network for mobile health monitoring tested accuracy in measurement of body heart rate, saturation of oxygen, blood pressure and skin temperature (Wannenburg & Malekian, 2015). (Santos et al., 2016) assessed the performance of mobile based system with parameters such as power consumption, accuracy of remote monitoring services and interoperability with other systems via Bluetooth. (Minutolo et al., 2015)

evaluated the effectiveness of proposed remote health monitoring application for monitoring cardiovascular diseases on four different mobile devices in terms of memory usage and response time. (Obermeier et al., 2016) evaluated the accuracy of the underlying machine learning algorithm for the proposed system which intend to classify different infectious and inflammatory diseases among children as aseptic meningitis, encephalitis, myelitis, and acute disseminated encephalomyelitis (ADEM) at the point of care. (Bruin et al., 2015) assessed the feasibility of the proposed system via qualitative survey based on a three-month trial period. (Lim et al., 2015; Vedanthan et al., 2015) conducted in-depth usability and feasibility testing of their proposed mobile based decision support system among intended users. In a typical hospital ward setting, enacting mobile wireless infrastructure and associated computing devices comes with their own unique challenges (Heslop et al., 2010).

Above studies not only discuss the need for proper evaluation of mobile based CDSS but also stress that the use of mobile based decision support systems in healthcare setting pose many challenges and face several practical limitations, which must be addressed before their widespread adoption and use. Thus, the field of mobile based DSS is slowly but steadily maturing in terms of satisfying users of these systems. These studies also highlight that adoption, continued usage and assimilation of such systems in daily workflow routines is still an area needing much attention and research from both medical informatics experts as well as system developers.

Impact on clinical outcomes

Studies under our review list many potential benefits of mobile clinical decision support systems in improving clinical outcomes. These benefits include reduced medication dosing errors (Palazuelos et al., 2013; Sadasivam & Gathibandhe, 2012; Tseng & Wu, 2014), correct recognition of physiological activities in remote healthcare settings (Zhang et al., 2016), accurate fall detection in real time in remote settings (Santos et al., 2016), reduction in cognitive load on health care professionals (Varshney, 2014), improved personalized physical activity and dietary suggestions (Rabbi et al., 2015), successful identification of medical stress (Wannenburg & Malekian, 2015), increased efficiency of routine work of healthcare workers (Madon, Amaguru, et al., 2014), higher triage accuracy,(Michalowski et al., 2005), correct and accurate classification of disease cases (Obermeier et al., 2016) and better diagnosis (Cato et al., 2014). 2 studies proposed a model or a design which is more effective for providing higher security and better performance (Lin et al., 2013; Varshney, 2014). (Minutolo et al., 2015) implemented a system capable of effective remote health monitoring for cardiovascular disease. Thus, we can infer that these systems have a positive impact on clinical outcomes.

Some studies emphasized the importance of integrating mobile based decision support tool with the workflow of healthcare workers. One study indicated that providing mobile phones to volunteer health workers resulted in increased efficiency of routine work, motivation and self-esteem (Madon, Olanya, et al., 2014). (Raghu et al., 2015) found that clinical decision support tools could be easily integrated into the workflow of healthcare workers. One study found that the inclusion of reminder for nurses to screen tobacco patients and inclusion of guideline based recommendation in mobile DSS applications reduced racial or ethnic disparities in screening (Cato et al., 2014). It also reduced barriers related to time, training and familiarity with resources available for such screening.

Although the studies in our review highlight many positive results due to the use of such systems, none of them relate these outcomes to cost savings and/or impact on mortality rate, which may be explored in future research.

Challenges and practical considerations

Some of the challenges and practical issues discussed in the articles under review are: usability issues, issues with acceptability and utility, lack of functionalities and technical issues.

Usability issue with small screen size is mentioned in 2 studies. (Varshney, 2014) highlights difficulty encountered in decision making by practitioners due to small screen size of the mobile device. This study suggests the need to design better user interface for mobile based CDSS to reduce the cognitive load on the user. Similarly (Dunsmuir et al., 2014) mentions entering of patient information through small key

pad of the mobile device as one of the most time-consuming task while using the system. This study also mentions the high learning curve involved in using small mobile devices since many professionals or healthcare workers lack experience of using smartphones or at least had no prior experience with data collection using mobile applications. Similar concern is also expressed in another article which mentions initial difficulty in learning to navigate the application, missing of certain common patient complaints in the system and inability to save patient information for follow-up visits (Knoble & Bhusal, 2015). Issues with user acceptance and usability are also discussed in other articles (Lim et al., 2015; Mirkovic, Kaufman, & Ruland, 2014; Vedanthan et al., 2015).

Challenges with acceptability and utility have also been highlighted. For example, the need for presenting complex medical information in easily comprehendible manner is mentioned in (Madon, Amaguru, et al., 2014). Another study performed a three-month pilot clinical trial to test the feasibility of the system (Bruin et al., 2015). (Raghu et al., 2015) performs pilot testing on 292 individuals with high risk of cardiovascular diseases for the preliminary acceptability, utility and efficiency of a mobile based point-of-care clinical decision support tool in a limited resource rural setting and found the tool to be feasible for use and easy to be integrated into the existing workflow of healthcare providers.

Lack of useful functionality is also emphasized in some studies. One study mentions the lack of use of mobile CDSS when the use is not mandatory (Knoble & Bhusal, 2015). The primary reasons cited by the health care workers in this study for lack of adoption are lack of time and inadequacy of the system in diagnosing complicated real life cases. A second study also found the functionalities provided by m-health DSS to be too primitive to be useful in most practical real-life scenarios (Vedanthan et al., 2015). The feasibility study carried out in (Vedanthan et al., 2015) demonstrates the need for incorporating several additional features into the system. This study also found that a frequent barrier to usage of tool by nurses is that many consider it as an extra burden when they are already overburdened with the normal workload. Need for enhancing tool functionalities, changes to existing workflow in public health care clinics and their staff, addressing supply chain barriers in medication supply as recommended by the CDSS, use of innovative strategies to improve treatment adherence at the patient side and providing sufficient training to front line health care workers in rural areas have been recommended as critical to widespread adoption of mobile CDSS (Praveen et al., 2014). (Lin et al., 2013) calls for design and implementation of mobile CDSS with privacy preserving capabilities. (Han et al., 2010) stressed the need for enhanced security and reliability, in addition to basic functionalities offered by the system. Technical limitations of mobile based systems such as limited network availability, transmission error detection and learning curve involved while interacting initially with the system were also mentioned (Vedanthan et al., 2015). Another study highlighted practical issues in mobile health domain such as poor cellular signals, bad lighting and frequent work flow interruptions (Olivia et al., 2014).
Thus, as pointed out by the above studies, some of these systems suffer not only from a lack of much needed contextual functionalities but also need enhanced security and privacy features. These are some critical factors hindering the widespread adoption of mobile CDSS.

Behavioral Issues

Several behavioral issues have been identified and discussed in some studies from the perspectives of practitioners, patients and community healthcare workers. One study discusses physician's perspective on the use of digital tools by patients for making health related decisions and self-medication help (van Mierlo, Fournier, & Fedorak, 2015). Authors in this study found that although the trend of current mobile based clinical decision support tools is towards concordance or shared decision making between physicians and patients, physicians nevertheless prefer digital tools which are regulated and compliant with medical practices where patients still take orders from the medical professionals regarding medication practices.

(Madon, Amaguru, et al., 2014) mentions improvement in self-esteem and motivation of health care workers because of using mobile based decision support system. (Praveen et al., 2014) found an increase in motivation of health care workers to perform cardio vascular screening using mobile platforms in remote rural sites. Similarly (Knoble & Bhusal, 2015) reveals that majority of the patients expressed confidence in the treatment procedure when health workers used mobile based diagnostic tools.

Contrary to above examples of positive behavioral outcomes (Vedanthan et al., 2015) found that some patients felt that tablet based decision support system used by nurses interfered with the emotional

relationship they had with nurses when traditional methods of treatment were used. Nurses in this study also point out that the initial use of the tool slowed down the encounter with patients since nurses had to focus on the device instead of patient, thus missing important non-verbal cues. Despite these issues, the study also found that the nurses felt empowered as the system not only provided recommendations for treatments but also offered justifications for the recommendations.

To summarize, the studies under this systematic review provide mixed results in terms of empowerment of healthcare providers and the dynamics of their relationship with patients. Thus, more studies in this domain are needed to gain further insight into social issues involving the role of mobile-based decision support systems on patient-provider relationship.

Limitations

This review covered only peer reviewed journal articles published in the English language. Thus, the exclusion of non-English language reports as well as working papers and conference proceedings may be considered as a limitation of our research. Furthermore, heterogeneity across study designs, sample sizes and research methodologies didn't allow us to make direct comparison of all studies. However, we could compare subsets of research reports that shared similar characteristics. Finally, note that the findings of any systematic review depend solely on the scope and quality of included studies. Our review is no exception to this limitation.

Conclusion

In this report, we reviewed 29 journal articles published in the last decade in mobile clinical decision support systems. Some of these studies carried out in resource limited settings suggest that such tools offer a viable option for remote health monitoring of patients. We found that any advantages of such systems must be weighed against usability, feasibility and practical considerations. Hence, the evolving nature of such systems may pose a challenge towards widespread adoption and positive outcomes in near future. Also, the emergence of personalized health systems and mobile health apps is leading to shared decision making, which not only involve community health care workers, nurses and physicians but patients as well. This fresh perspective on contemporary decision support systems in health care setting is altering the traditional view where physicians have been regarded as the sole authority of decision making.

REFERENCES

Bakken, S., Jia, H., Chen, E. S., Choi, J., John, R. M., Lee, N., … Roberts, W. D. (2014). The Effect of a Mobile Health Decision. *TJNP: The Journal for Nurse Practitioners*, *10*(10), 774–780. https://doi.org/10.1016/j.nurpra.2014.07.017

Braun, R., Lasway, C., Agarwal, S., Engle, K. L., Silas, L., Mwakibete, A., … Braun, R. (2016). An Evaluation of a Family Planning Mobile Job Aid for Community Health Workers in Tanzania. *Contraception*. https://doi.org/10.1016/j.contraception.2016.03.016

Bruin, J. S. De, Schuh, C., Seeling, W., Luger, E., Gall, M., Hütterer, E., … Schindler, K. (2015). Assessing the feasibility of a mobile health-supported clinical decision support system for nutritional triage in oncology outpatients using Arden Syntax. *Artificial Intelligence In Medicine*, 1–9. https://doi.org/10.1016/j.artmed.2015.10.001

Cato, K., Hyun, S., & Bakken, S. (2014). Response to a Mobile Health Decision-Support System for Screening and Management of Tobacco Use. *Oncology Nursing Forum*, *41*(2), 145–152.

Chaudhry, B., Wang, J., Wu, S., Maglione, M., Mojica, W., Roth, E., … Shekelle, P. G. (2006). Systematic review: impact of health information technology on quality, efficiency, and costs of medical care. *Annals of Internal Medicine*, *144*(10), 742–752.

Choudhry, N. K., Fletcher, R. H., & Soumerai, S. B. (2005). Systematic review: the relationship between clinical experience and quality of health care. *Annals of Internal Medicine*, *142*(4), 260–273.

Crawford, M. J., Rutter, D., Manley, C., Weaver, T., Bhui, K., Fulop, N., & Tyrer, P. (2002). Systematic review of involving patients in the planning and development of health care. *Bmj*, *325*(7375), 1263.

Deeks, J. J. (2001). Systematic reviews of evaluations of diagnostic and screening tests. *BMJ: British Medical Journal*, *323*(7305), 157.

Dunsmuir, D. T., Payne, B. A., Cloete, G., Petersen, C. L., Matthias, G., Lim, J., … Ansermino, J. M. (2014). Development of mHealth Applications for Pre-Eclampsia Triage. *IEEE Journal of Biomedical and Health Informatics*, *18*(6), 1857–1864.

Fayn, J., & Rubel, P. (2010). Toward a Personal Health Society in Cardiology. *IEEE Transactions on Information Technology in Biomedicine*, *14*(2), 401–409.

Garg, A., & Adhikari, N. (2005). Effects of computerized clinical decision support systems on practitioner performance and patient outcomes: a systematic review. *Jama*, *293*(10), 1223–1238.

Han, D., Lee, M., & Park, S. (2010). THE-MUSS : Mobile u-health service system. *Computer Methods and Programs in Biomedicine*, *97*, 178–188. https://doi.org/10.1016/j.cmpb.2009.08.004

Heslop, L., Weeding, S., Dawson, L., Fisher, J., & Howard, A. (2010). Implementation Issues for Mobile-Wireless Infrastructure and Mobile Health Care Computing Devices for a Hospital Ward Setting. *Journal of Medical Systems*, *34*, 509–518. https://doi.org/10.1007/s10916-009-9264-y

Hyun, Sookyunk Nirenberg, Anita Staats, Jo Anne Bakken, S. (2013). Mobile Health-Based Resources for Smoking Cessation Resources. *Oncology Nursing Forum*, *40*(4).

Knoble, S. J., & Bhusal, M. R. (2015). Electronic diagnostic algorithms to assist mid-level health care workers in Nepal : A mixed-method exploratory study. *International Journal of Medical Informatics*, *84*(5), 334–340. https://doi.org/10.1016/j.ijmedinf.2015.01.011

Liberati, A., Altman, D. G., Tetzlaff, J., Mulrow, C., Gøtzsche, P. C., Ioannidis, J. P., … Moher, D. (2009). The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. *PLoS Med*, *6*(7), e1000100.

Lim, J., Cloete, G., Dunsmuir, D. T., Payne, B. A., & Scheffer, C. (2015). Usability and Feasibility of PIERS on the Move : An mHealth App for Pre-Eclampsia Triage. *JMIR mHealth and uHealth*, *3*, 1–10. https://doi.org/10.2196/mhealth.3942

Lin, H., Shao, J., Zhang, C., & Fang, Y. (2013). CAM : Cloud-Assisted Privacy Preserving Mobile Health Monitoring. *IEEE Transactions on Information Forensics and Security*, *8*(6), 985–997.

Madon, S., Amaguru, J. O., Malecela, M. N., & Michael, E. (2014). Can mobile phones help control neglected tropical diseases? Experiences from Tanzania. *Social Science & Medicine (1982)*, *102*, 103–10. https://doi.org/10.1016/j.socscimed.2013.11.036

Madon, S., Olanya, J., Ntuli, M., & Michael, E. (2014). Social Science & Medicine Can mobile phones help control neglected tropical diseases ? Experiences from Tanzania. *Social Science & Medicine*, *102*, 103–110. https://doi.org/10.1016/j.socscimed.2013.11.036

Martínez-Pérez, B., de la Torre-Díez, I., López-Coronado, M., Sainz-de-Abajo, B., Robles, M., & García-Gómez, J. M. (2014). Mobile Clinical Decision Support Systems and Applications: A Literature and Commercial Review. *Journal of Medical Systems*, *38*(1). https://doi.org/10.1007/s10916-013-0004-y

Michalowski, W., Farion, K. E. N., Pike, J., & Rubin, S. (2005). DEVELOPMENT OF A DECISION ALGORITHM TO SUPPORT EMERGENCY TRIAGE OF SCROTAL PAIN AND ITS IMPLEMENTATION IN THE MET SYSTEM. *INFOR*, *43*(4), 287–301.

Michalowski, W., & Ph, D. (2005). Design and Development of a Mobile System for Supporting Emergency Triage. *Methods of Information in Medicine*, *44*(1), 14–24.

Minutolo, A., Esposito, M., & Pietro, G. De. (2015). Design and validation of a light-weight reasoning system to support remote health monitoring applications. *Engineering Applications of Artificial Intelligence*, *41*, 232–248. https://doi.org/10.1016/j.engappai.2015.01.019

Mirkovic, J., Kaufman, D. R., & Ruland, C. M. (2014). Supporting cancer patients in illness management: usability evaluation of a mobile app. *JMIR mHealth and uHealth*, *2*(3), e33. https://doi.org/10.2196/mhealth.3359

Modre-osprian, R., Pölzl, G., & Heidt, A. V. O. N. D. E. R. (2014). Closed-Loop Healthcare Monitoring in a Collaborative Heart Failure Network. *Student Health Technology and Informatics*, *198*, 17–24. https://doi.org/10.3233/978-1-61499-397-1-17

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., Group, P., & others. (2009). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med*, *6*(7), e1000097.

Mulrow, C. D. (1994). Rationale for systematic reviews. *BMJ: British Medical Journal*, *309*(6954), 597.

Obermeier, P., Muehlhans, S., Hoppe, C., Karsch, K., Tief, F., Seeber, L., … Rath, B. (2016). Enabling Precision Medicine With Digital Case Classification at the Point-of-Care. *EBioMedicine*, *4*, 191–196. https://doi.org/10.1016/j.ebiom.2016.01.008

Olivia, V., Okyere, P. B., Kanter, A. S., & Bakken, S. (2014). A Usability Study of a Mobile Health Application for Rural Ghanaian Midwives. *Journal of Midwifery and Women's Health*. https://doi.org/10.1111/jmwh.12071

Oxman, A. D., Cook, D. J., Guyatt, G. H., Bass, E., Brill-Edwards, P., Browman, G., … others. (1994). Users' guides to the medical literature: VI. How to use an overview. *Jama*, *272*(17), 1367–1371.

Palazuelos, D., Diallo, A. B., Palazuelos, L., Carlile, N., & Jonathan, D. (2013). User Perceptions of an mHealth Medicine Dosing Tool for Community Health Workers Corresponding Author : *JMIR mHealth and uHealth*, *1*(1), 1–15. https://doi.org/10.2196/mhealth.2459

Praveen, D., Patel, A., Raghu, A., Clifford, G. D., & Pallab, K. (2014). SMARTHealth India : Development and Field Evaluation of a Mobile Clinical Decision Support System for Cardiovascular Diseases in Rural India Corresponding Author : Registration : *JMIR mHealth and uHealth*, *2*(4). https://doi.org/10.2196/mhealth.3568

Rabbi, M., Pfammatter, A., Zhang, M., Spring, B., Choudhury, T., & Hall, G. (2015). Automated Personalized Feedback for Physical Activity and Dietary Behavior Change With Mobile Phones : A Randomized Controlled Trial on Adults. *JMIR mHealth and uHealth*, *3*(2). https://doi.org/10.2196/mhealth.4160

Raghu, A., Praveen, D., Peiris, D., Tarassenko, L., & Clifford, G. (2015). Engineering a mobile health tool for resource-poor settings to assess and manage cardiovascular disease risk: SMARThealth study. *BMC Medical Informatics and Decision Making*, 1–15. https://doi.org/10.1186/s12911-015-0148-4

Sadasivam, R. S., & Gathibandhe, V. (2012). Development of a Point-of-Care HIV / Aids Medication Dosing Support System Using the Android Mobile Platform. *Journal of Medical Systems*, *36*, 1583–1591. https://doi.org/10.1007/s10916-010-9619-4

Sannino, G., & Pietro, G. De. (2014). A mobile system for real-time context-aware monitoring of patients' health and fainting. *International Journal of Data Mining and Bioinformatics*, *10*(4), 407–423.

Santos, J., Rodrigues, J. J. P. C., Bruno, M. C., Casal, J., Saleem, K., Denisov, V., … Denisov, V. (2016). An IoT-based Mobile Gateway for Intelligent Personal Assistants on Mobile Health Environments. *Journal of Network and Computer Applications*. https://doi.org/10.1016/j.jnca.2016.03.014

Sim, I., Gorman, P., Greenes, R. A., Haynes, R. B., Kaplan, B., Lehmann, H., & Tang, P. C. (2001). Clinical decision support systems for the practice of evidence-based medicine. *Journal of the American Medical Informatics Association*, *8*(6), 527–534.

Sprague Jr, R. H., & Carlson, E. D. (1982). *Building effective decision support systems*. book, Prentice Hall Professional Technical Reference.

Tranfield, D., Denyer, D., & Smart, P. (2003). Towards a methodology for developing evidence-informed management knowledge by means of systematic review. *British Journal of Management*, *14*(3), 207–222.

Tseng, M., & Wu, H. (2014). A cloud medication safety support system using QR code and Web services for elderly outpatients. *Technology and Healthcare*, *22*(110), 99–113. https://doi.org/10.3233/THC-140778

van Mierlo, T., Fournier, R., & Fedorak, R. (2015). Don't forget the doctor: gastroenterologists' preferences on the development of mHealth tools for inflammatory bowel disease. *JMIR mHealth and uHealth*, *3*(1), e5. article.

Varshney, U. (2014). A model for improving quality of decisions in mobile health. *Decision Support Systems*, *62*, 66–77. https://doi.org/10.1016/j.dss.2014.03.005

Vedanthan, R., Blank, E., Tuikong, N., Kamano, J., Misoi, L., Tulienge, D., … Were, M. C. (2015). Usability and feasibility of a tablet-based Decision-Support and Integrated Record-keeping (DESIRE) tool in the nurse management of hypertension in rural western Kenya. *International Journal of Medical Informatics*, *84*(3), 207–219. https://doi.org/10.1016/j.ijmedinf.2014.12.005

Wannenburg, J., & Malekian, R. (2015). Body Sensor Network for Mobile Health Monitoring, a Diagnosis and Anticipating System. *IEEE Sensors Journal*, *15*(12), 6839–6852.

Zhang, W., Thurow, K., & Stoll, R. (2016). A Context-Aware mHealth System for Online Physiological Monitoring in Remote Healthcare Related Work System structure. *International Journal of Computers Communications and Control*, *11*(February), 142–156.