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Review Article

Using mobile phone applications in engaging nurses for preventing healthcare-associated infections: A systematic review

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ABSTRACT

Background & Aim: Prevention of healthcare-associated infections targets health workers. Considering the crucial role of nurses, potential applications of mobile phone-based interventions are innovative, attractive, and easily accessible. This study synthesizes mobile applications with the involvement of nurses or nursing students in outcomes to prevent healthcare-associated infections and their implications.
Methods & Materials: Systematic review, database searches included: SCOPUS, EBSCO MEDLINE, PubMed, ProQuest, Institute of Electrical and Electronics Engineers, and SagePUb. Population involved nurses or nursing students with mobile-based interventions about healthcare-associated infections. Quantitative design focused on publications between 2015-2021. Methodological quality applied the Cochrane and the National Heart, Lung, and Blood Institute tools. Analysis used narrative synthesis.
Results: 11 studies met inclusion criteria from 1,792. Study populations were heterogeneous. Mobile phone interventions included: short message service (18.2%), (9.1%), mobile and computer access (18.2%), and iOs/Android-based (27.3%). healthcare-associated infections prevention focused on: surgical site infections (54.5%), central line-associated bloodstream infections (9.1%), catheter-associated urinary tract infections (9.1%), antimicrobials (9.1%), knowledge, attitude, and practice towards healthcare-associated infections (18.2%). Most bias risks were moderate to high. Participants showed positive responses. All studies described problems in implementing healthcare-associated infections applications. Five studies reported estimated cost savings.
Conclusion: Using mobile phone applications has involved nurses as researchers, participants, and intervention providers to patients. The impact is promising in preventing healthcare-associated infections. Response of user is influenced by technology familiarity, which involves interactive features and problem anticipation. This review showed significant cost savings, so stakeholders and future research plans can consider it.

Introduction

The most common side effects affecting hospitalized patients are drug side effects, healthcare-associated infections (HCAIs), and surgical complications (1,2). The HCAIs affect millions of patients and cause tremendous economic burden, with case fatality rates ranging from 2.3% to 14.4% worldwide (3,4). Most HCAIs are associated with invasive procedures, such as central line-associated bloodstream infections (CLABSI), catheter-associated urinary tract infections (CAUTI), ventilator-associated pneumonia (VAP), and surgical site infections (SSI) (3). The incidence of HCAIs worsens with increasing rates of antimicrobial resistance (AMR) (5). Healthcare organizations have implemented clinical best practices (CBP) with various strategies to prevent HCAIs.

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These include hand hygiene and sanitation, screening (4,6), and developing guidelines regarding prescribing, and feedback activities (5,7). Implementing the HCAIs strategy are primarily health workers, one of which is nurses as key members because they represent the most significant proportion of hospital staff. Nurses are significantly involved in the principles of HCAIs prevention practices (8,9). However, the strategies in these studies faced problems related to maintaining their continued involvement (5,7). The main challenge is to find effective ways to increase awareness, compliance, motivation, engagement, understanding, and practice of preventing HCAIs (10).

As one potential solution to this challenge, the mobile phone application (app) is one of the considerations with an innovative approach to attract and maintain attention, simple, helpful, quick access in clinical decisions (11,12), and encourage the participation of nurses as Health Care Workers (HCW) and patients in preventing HCAIs (13). Nearly all (89%) health professionals use mobile phone apps (14) to access medical information, clinical tools and maintain communication with patients (3,11,15,16). Recent research supported by other studies revealed mobile apps as an effective tool for transferring knowledge and decisions in nursing or clinical education. (22, 23).

Literature on mobile phone apps to prevent HCAIs is limited. The existing reviews include a study from Schnall and Iribarren in 2015 that found 17 relevant apps for HCAIs prevention. However, this study is only limited to the app's function and potential, explored from three app stores: iTunes Store, Google Play Store Android, and Amazon Appstore (16). There is no information on implementing the app in health care settings and participant users. The recent study revealed by Bentvelsen et al. in 2021 assesses the clinical functions, quality, and usefulness of apps related to HCAIs. Results show there are 28 apps. Although potentially clinically relevant applications have been identified, they are still limited. There is no information on developing, implementing the app, and involving the participants in clinical settings. Researchers only searched and presented results on 'grey' data sources such as application stores (19). To our knowledge, studies discussing the use of apps are still limited related to the prevention of HCAIs highlighting the involvement of nurses or nursing students as participants or developers or providers of interventions in health care settings by searching using electronic journal databases. We were interested in conducting this systematic review to explore and synthesize information to understand the use of the HCAIs app by nurses or nursing students by identifying knowledge gaps, practices, user responses, challenges, and implications of nursing.

Methods

The systematic review study was carried out to review the use of mobile phone apps by nurses or nursing students in outcomes to prevent HCAIs and their implications. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses 2020 (PRISMA) (20) was used as a guide for reporting these systematic reviews.

Inclusion and exclusion criteria

The selection and search criteria for this systematic review using the PICO (population, intervention, comparison, and outcome) (21): population (P): involving nurses or nursing students in the study either as participants: single participant focus on nurses. or part of HCW, or intervention

provider for patient, intervention (I): use of mobile phone-based interventions, comparison (C): other groups or control groups other than those receiving the mobile phone intervention, outcome (O): primary: prevention or control of HCAIs (the authors not limited the types of HCAIs), and design (D): quantitative design (mix method, randomized controlled trials, quasi-experimental, pilot (RCT) and cohort, cross-sectional). With the publication date range between 2015-2021, the authors consider five years due to the rapid acceleration of digital technology development in a short time (22). Therefore, the latest research may be more relevant because it can provide valuable insights (23). The exclusion criteria were: (a) conference presentations, reviews, editorials, review articles, case reports, and case series, qualitative research, applied, development design, or protocols study that did not explain outcomes, (b) publication not in English, and (c) not a study with nursing implications.

Search strategy

A systematic review involved searching articles through electronic databases: SCOPUS, EBSCO MEDLINE, PubMed, ProQuest, Institute of Electrical and Electronics Engineers (IEEE), and SagePUb. Authors used "Google Scholar" to find grey literature (24). Authors discussed determining synonyms related terms with keyword terms: "Nurses" [Mesh] OR "Licensed Practical Nurses" [Mesh] OR "Nursing" [Mesh] OR "Nursing Care" [Mesh] OR "Nursing" [Subheading] OR "Nursing Staff" [Mesh] OR "Students, Nursing" [Mesh] AND "mobile apps" OR "smartphone" OR "mobile" OR "app*" OR "m-health" OR "game" AND "cross-infection prevention*" OR "Infection Prevention" OR "Infection Control". Keywords used Boolean operators (AND/OR) and asterisks to broaden and narrow the search. The search string was constructed using a combination of MeSH and Thesaurus subject headings and free-text keywords (Supplementary Appendix 1).

Supplementary appendix 1. Full search strategies for all resources

1. Search strategy for PubMed (update: Aug 21, 2021)

Search terms	Query	Actions	Items found
#1 AND #2 AND #3 AND #4	(("Nurses" [Mesh] OR "Licensed Practical Nurses"[Mesh] OR "Nursing"[Mesh] OR "Nursing Care"[Mesh] OR "Nursing" [Subheading] OR "Nursing Staff"[Mesh] OR "Students, Nursing"[Mesh] OR "Nurse Clinicians"[Mesh] OR "Nurse Specialists "[Mesh] OR "Nurses" OR "Licensed Practical Nurses" OR "Nursing Care" OR "Nursing" OR "Nursing Staff" OR "Nursing Students" OR "Nurse Specialists") AND ("mobile phone" OR "mobile application" OR "mobile" OR "smart" OR "cell*" OR "smartphone*" OR "cellphone*" OR "iPhone*" OR "ipad*" OR "portabl*" OR "android" OR "digital*" OR "portable"OR "phone*" OR "telephon*" OR "app*" OR "apps" OR "application*" OR "software*" OR "device*" OR "tablet*".)) AND ("Practice Patterns, Nurses'"[Mesh] OR "Infection Control+" OR "Handwashing+" OR "infection prevention*" OR "infection control*" OR "cross-infection prevention*" OR "cross-infection control*" OR "icln" OR "ipc" OR "handwash*" OR"hand wash*" OR "hand hygien*" OR "handhygien*" OR "disinfecti*" OR "co wash*".)	Filters: Full text, Journal Article, in the last 5 years, English	834
#4	(("Nurses" [Mesh] OR "Licensed Practical Nurses"[Mesh] OR "Nursing"[Mesh] OR "Nursing Care"[Mesh] OR "Nursing" [Subheading] OR "Nursing Staff"[Mesh] OR "Students, Nursing"[Mesh] OR "Nurse Clinicians"[Mesh] OR "Nurse Specialists "[Mesh] OR "Nurses" OR "Licensed Practical Nurses" OR "Nursing Care" OR "Nursing" OR "Nursing Staff" OR "Nursing Students" OR "Nurse Specialists".) AND ("mobile phone" OR "mobile application" OR "mobile" OR "smart" OR "cell*" OR "smartphone*" OR "cellphone*" OR "iPhone*" OR "ipad*" OR "portabl*" OR "android" OR "digital*" OR "portable"OR "phone*" OR "telephon*" OR "app*" OR "apps"	Filters: Full text, Journal Article, in the last 5 years, English	2,036

	OR "application*" OR "software*" OR "device*" OR "tablet*".)) AND ("Practice Patterns, Nurses"[Mesh] OR "Infection Control+" OR "Handwashing+" OR "infection prevention*" OR "infection control*" OR "cross-infection prevention*" OR "cross-infection control*" OR "icln" OR "ipc" OR "handwash*" OR"hand wash*" OR "hand hygien*" OR "handhygien*" OR "disinfecti*" OR "co wash*".)		
#3	"Practice Patterns, Nurses"[Mesh] OR "Infection Control+" OR "Handwashing+" OR "infection prevention*" OR "infection control*" OR "cross-infection prevention*" OR "cross-infection control*" OR "icln" OR "ipc" OR "handwash*" OR"hand wash*" OR "hand hygien*" OR "handhygien*" OR "disinfecti*" OR "co wash*".	Filters: Full text, Journal Article, in the last 5 years, English	132,573
#2	"mobile phone" OR "mobile application" OR "mobile" OR "smart" OR "cell*" OR "smartphone*" OR "cellphone*" OR "iPhone*" OR "ipad*" OR "portabl*" OR "android" OR "digital*" OR "portable"OR "phone*" OR "telephon*" OR "app*" OR "apps" OR "application*" OR "software*" OR "device*" OR "tablet*".	Filters: Full text, Journal Article, in the last 5 years, English	8,440,570
#1	"Nurses" [Mesh] OR "Licensed Practical Nurses"[Mesh] OR "Nursing"[Mesh] OR "Nursing Care"[Mesh] OR "Nursing" [Subheading] OR "Nursing Staff"[Mesh] OR "Students, Nursing"[Mesh] OR "Nurse Clinicians"[Mesh] OR "Nurse Specialists "[Mesh] OR "Nurses" OR "Licensed Practical Nurses" OR "Nursing Care" OR "Nursing" OR "Nursing Staff" OR "Nursing Students" OR "Nurse Specialists".	Filters: Full text, Journal Article, in the last 5 years, English	857,352

Noted:
[Mesh]= Medical subject headings
[tiab]= words in title OR abstract

2. Search strategy for Ebsco/Medline (Mar 10, 2021)

Search terms	Query	Actions	Items found
#1 AND #2 AND #3	(MH "Nurses+" OR MH "Nurses by Educational Level+" OR MH "Nurses by Role+" OR MH "Advanced Practice Nurses+" OR MH "Pediatric Nurse Practitioners+" OR MH "Nurse Practitioners+" OR MH "Nurses by Specialty+" OR MH "Nurses, Other+" OR MH "Nurse Consultants+" OR TI(nurse*) OR AB(nurse*)) AND (MH "mobile phone+" OR "mobile application+" OR "mobile" OR "smart" OR "cell*" OR MH "smartphone*+" OR "cellphone*" OR "iPhone*" OR "ipad*" OR "portabl*" OR "android" OR "digital*" OR "portable"OR "phone*" OR "telephon*" OR "app*" OR "apps" OR MH "application*+" OR "software*" OR "device*" OR "tablet*")) AND (MH "Infection Control+" OR MH "Handwashing+" OR TI("infection prevention*" OR "infection control*" OR "crossinfection prevention*" OR "crossinfection control*" OR icln OR ipc OR handwash* OR hand wash* OR "hand hygien*" OR handhygien* OR disinfecti* OR "co wash*") OR AB("infection prevention*" OR "infection control*" OR "cross-infection prevention*" OR "cross-infection control*" OR icln OR ipc OR OR handwash* OR hand wash* OR "hand hygien*" OR handhygien* OR disinfecti* OR "co wash*"))	Filters: Full Text; Date of Publication: 20150101-20211231; English Language	184
#1 AND #2 AND #3	(MH "Nurses+" OR MH "Nurses by Educational Level+" OR MH "Nurses by Role+" OR MH "Advanced Practice Nurses+" OR MH "Pediatric Nurse Practitioners+" OR MH "Nurse Practitioners+" OR MH "Nurses by Specialty+" OR MH "Nurses, Other+" OR MH "Nurse Consultants+" OR TI(nurse*) OR AB(nurse*)) AND (MH "mobile phone+" OR "mobile application+" OR "mobile" OR "smart" OR "cell*" OR MH "smartphone*+" OR "cellphone*" OR "iPhone*" OR "ipad*" OR "portabl*" OR "android" OR "digital*" OR "portable"OR "phone*" OR "telephon*" OR "app*" OR "apps" OR MH "application*+" OR "software*" OR "device*" OR "tablet*")) AND (MH "Infection Control+" OR MH "Handwashing+" OR TI("infection prevention*" OR "infection control*" OR "crossinfection prevention*" OR "crossinfection control*" OR icln OR ipc OR handwash* OR hand wash* OR "hand hygien*" OR handhygien* OR disinfecti* OR "co wash*") OR AB("infection prevention*" OR "infection control*" OR "cross-infection prevention*" OR "cross-infection control*" OR icln OR ipc OR OR handwash* OR hand wash* OR "hand hygien*" OR handhygien* OR disinfecti* OR "co wash*"))	Filters: Full Text	396
#3	MH "Infection Control+" OR MH "Handwashing+" OR TI("infection prevention*" OR "infection control*" OR "crossinfection prevention*" OR "crossinfection control*" OR icln OR ipc OR handwash* OR hand wash* OR "hand hygien*" OR handhygien* OR disinfecti* OR "co wash*") OR AB("infection prevention*" OR "infection control*" OR "cross-infection prevention*" OR "cross-infection control*" OR icln OR ipc OR OR handwash*	Filters: Full Text Expanders: Also search within the full text of the articles; Apply equivalent subjects	11,484

	OR hand wash* OR "hand hygien*" OR handhygien* OR disinfecti* OR "co wash*")	Search modes: Find all my search terms	
#2	MH "mobile phone+" OR "mobile application+" OR "mobile" OR "smart" OR "cell*" OR MH "smartphone*+" OR "cellphone*" OR "iPhone*" OR "ipad*" OR "portabl*" OR "android" OR "digital*" OR "portable"OR "phone*" OR "telephon*" OR "app*" OR "apps" OR MH "application*+" OR "software*" OR "device*" OR "tablet*".	Filters: Full Text Expanders: Also search within the full text of the articles; Apply equivalent subjects Search modes: Find all my search terms	3,520,313
#1	MH "Nurses+" OR MH "Nurses by Educational Level+" OR MH "Nurses by Role+" OR MH "Advanced Practice Nurses+" OR MH "Pediatric Nurse Practitioners+" OR MH "Nurse Practitioners+" OR MH "Nurses by Specialty+" OR MH "Nurses, Other+" OR MH "Nurse Consultants+" OR TI(nurse*) OR AB(nurse*)	Filters: Full Text Expanders: Also search within the full text of the articles; Apply equivalent subjects Search modes: Find all my search terms	34,813

Noted: MH= keywords
+= keyword with explosion
TI= words in title
AB= words in abstract

3. Search strategy for Scopus (Mar 12, 2021)

Search term	Query	Items found
#1 AND #2 AND #3	**Limit to:** AND (LIMIT-TO (OA , "all")) AND (LIMIT-TO (PUBYEAR, 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR, 2019) OR LIMIT-TO (PUBYEAR, 2018) OR LIMIT-TO (PUBYEAR, 2017) OR LIMIT-TO (PUBYEAR, 2016) OR LIMIT-TO (PUBYEAR, 2015)) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (SRCTYPE, "j"))	221
#1 AND #2 AND #3	(ALL(Nurse* OR Nursing OR "Nursing Student*")) AND (TITLE-ABS-KEY(mobile OR m-Health OR smart OR cell* OR portabl* OR computer* OR android OR digital* OR portable OR phone* OR telephon* OR app OR apps OR application* OR software* OR device* OR tablet* OR assistant OR smartphone* OR cellphone* OR iPhone* OR ipad* OR handheld* OR hand-held*)) AND (ALL(Infection Control OR infection prevention* OR infection control* OR "cross-infection prevention*" OR "cross-infection control*" OR "Infection Prevention Performanc*" OR guideline* OR "decision AND making"))	706
#3	ALL (infection AND control OR infection AND prevention* OR infection AND control* OR "cross-infectionprevention*" OR "cross-infection control*" OR ‘‘infection AND prevention AND performanc*’’ OR guideline* OR "decision AND making")	57,233
#2	TITLE-ABS-KEY (mobile OR m Health OR smart OR cell* OR portabl* OR computer* OR android OR digital* OR portable OR phone* OR telephon* OR app OR apps OR application* OR software* OR device* OR tablet* OR assistant OR smartphone* OR cellphone* OR iphone* OR ipad* OR handheld* OR hand-held*)	23,026,480
#1	ALL (nurse* OR nursing OR "nursing AND student*")	310,210

4. Search strategy for Proquest (Mar 13 2021)

Search	Query	Items found
Filters	Year custom range: 2015-2021 Scholarly Journals Article English	83
1	ab(mobile apps OR mobile apps OR smartphone OR mobile OR apps OR mhealth OR game) AND (Infection Prevention OR Infection Control) AND ab(Nurses OR Nurse student)	136

Noted: ab= abstract

5. Search strategy for ScienceDirect (Mar 13, 2021)

Search	Query	Items found
Filters	Years: 2015-2021 Article type: Research articles Access type: Open access	440
1	(Nurses OR Nurse student) AND (smartphone OR mobile OR apps OR mHealth OR game) AND (Infection Prevention OR Infection Control).	11,253

6. Search strategy for IEEE (May 15, 2021)

Search	Query	Items found
Filters	Years: 2015-2021 Article type: Journals Access type: Open access only	7
1	All Metadata":smartphone OR "All Metadata":mobile OR "All Metadata":apps OR "All Metadata":mhealth OR "All Metadata":game) AND ("All Metadata":Infection Prevention OR "All Metadata":Infection Control	130

7. Search strategy for SagePub (May 15, 2021)

Search	Query	Items found
Filters	Years: 2015-2021 Only show Open Access	25
1	for [[Title smartphone] OR [Title mobile] OR [Title apps] OR [Title mhealth] OR [Title game*]] AND [Abstract infection] AND [[Abstract prevention] OR [Abstract infection]] AND [Abstract control]	65

Selection of studies

The total of 1,794 studies included 1,792 studies from primary database journals and two studies from grey literature "Google Scholar." All studies were entered into Mendeley or Zotero (database reference manager) and exported in CSV format to be filtered in Microsoft Excel sheets. The study screening process was done in Excel format, and reporting followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses flowchart 2020 (20). The study selection process from 1,761 studies (1,759 from electronic journal databases and two studies from the gray literature) was initiated by removing duplicates. All authors independently screened potentially relevant studies by title and abstract. We found 28 studies that were relevant and read in full text independently by both authors (YNF and KA). Then, the authors discuss and make a consensus if there is a disagreement and review the data together. Finally, there were 11 studies included in this systematic review (Figure 1).

Data extraction, analysis, and synthesis

We designed a data extraction table based on the PICO framework as a guide (25). The data extraction process used Microsoft Excel sheets and was compared, with differences resolved through discussion. The authors only conducted a systematic review, and it did not require a meta-analysis review due to the low number of studies and heterogeneity between studies design characteristics, population (nurses, patients, HCW, or both), and subpopulations (age, gender) and intervention (duration). Narrative syntheses were carried out to interpret the evidence findings, which included the general characteristics surrounding the elements of the PICO question framework. The authors synthesized by extracting data using a Microsoft Excel sheet and tested it on two included studies. We created metrics for each outcome, identifying and summarizing the synthesis and reporting results of the included studies. We discussed this during the synthesis process and were open to input.

Risk of bias and study quality

Authors assess study quality considering the Cochrane risk of bias for a

non-randomized study (ROBIN) and Risk of Bias for randomized controlled trial (RoB 2) (26,27), and study quality assessment tool for observational cohort and cross-sectional studies used by The National Heart, Lung, and Blood Institute (NHLBI) (34). ROBIN was assessed on seven domains. Moreover, the RoB 2 was evaluated across five biased domains. NHLBI tools were used to determine study quality with 14 criteria, and overall rating based on the items scored: 75%= good, 50-75% = fair, <50%= poor (28).

The results with a more significant risk of bias, the lower the research quality rating. The authors used the risk of bias visualization tool from Bristol University and modified it with excel (29).

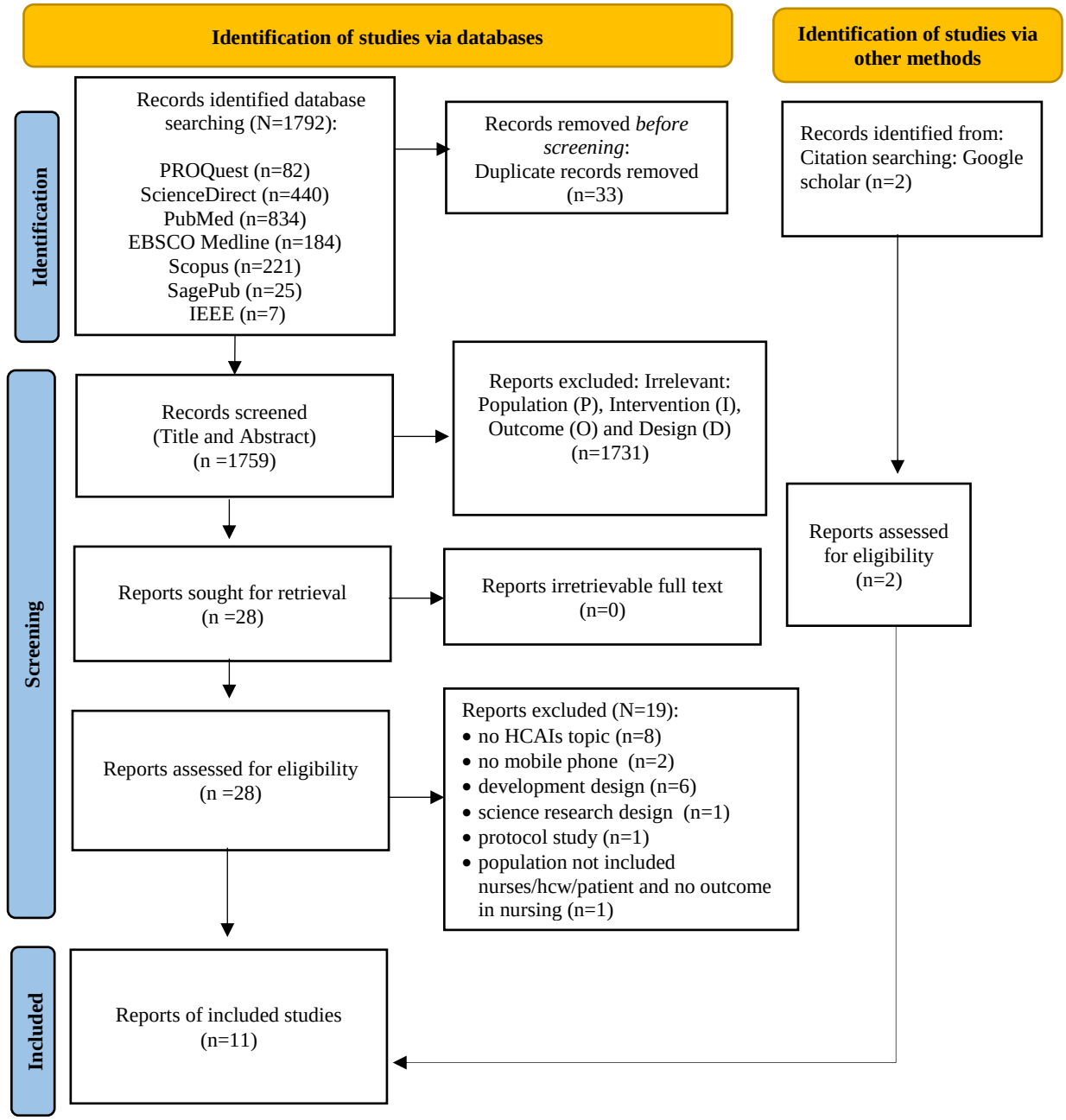

Figure 1. Flow diagram used in selecting studies using PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) (20)

Results

Identified and characteristics of the included studies

The authors first obtained 1,792 articles through all databases. Only 11 studies met the inclusion criteria in the systematic review. The summarized of included studies are in Table 1. Of the 11 studies, four (36.4%) of the lead authors were nurses (37-40). The total number of participants is 2,247. The study population was heterogeneous, but all involved nurses either as participants or researchers or as intervention providers to patients. Five studies (45.5%) involved patient study participants (30,31,34-36), two studies (18.2%) of HCW (37,38), and three studies (27.3%) focus on nurses as participants (32,33,39). One study (9.1%) study with patients and HCW participants (40). There is no study with participants as nursing students. The majority genders were 55% female (30) and 69% (33), and 75% were male (34). The age range of participants reported by seven studies was between 18-70 years (30,31,33-36,40). Six studies (54.5%) were date publications 2018-2020 (31-33,35,39,40). Countries were conducted research, mostly in the US, three studies (27.3%) (32,37,39). Related to study design: Most [5] studies (45.5%) were nonrandomized trials (32,33,37–39). Interventions were using a mobile phone: short message service (SMS) (1/11, 9.1%) (33) and hardware and SMS (1/11, 9.1%) (38), hardware and mobile app (1/11, 9.1%) (37), two studies phone calls (2/11, 18.2%) (31,34), cloud-based (1/11, 9.1%) (32), mobile and computer access (2/11, 18.2%) (39,40), app iOs/Android-based (3/11, 27.3%) (30,35,36), with most using the intervention for prevention of HCAIs: SSI monitoring (6/11, 54.5%): 5 studies in postoperative patients (36.40-42) and 1 study assessing wounds by nurses (43). The language used in the intervention was mostly used English in 5 studies (45.5%) (32,36,37,39,40). Six studies (54.5%) of the operating system were in all mobile phones (31-34,36,38).

Table 1. Descriptive summary of studies selected (n=11)

No	Author (year), Country	Study design	Participants and setting	Sample size (n), Age Mean(SD)/Median (min-max) and Sex M/F		Interventions (Operating system (OS) and App name)		Language, category, and feature intervention	Duration (weeks)	Follow up	Outcome(s) and measure(s)	Major finding
				Interventions group (IG)	Control group (CG)	IG	CG					
The nurse identified as the lead author												
1	Jaenssson et al. (2017)/ Swede n (30)	Multi-center RCT	Post-operative patients. Hospital	494 Age: Mean 45 (15)/46 (18–81). Sex: M/F 220(45)/274 (55)	503 Age: Mean 46 (15)/ 47(18 –82). Sex M/F 235(47)/268(53)	Not mentioned OS mobile: RAPP Apps Daily reminder to answers in-app.	Standard care as usual care Patients fill out days 7 and 14 on a paper-based.	Swedish HCAIs: SSI Post-operative recovery app: Twenty-four negative word items on the phone screen scored on a visual analog scale. Offers YES/NO for nurses to call.	2	Day 7 and Day 14	1. Recovery post-operative patients Day 7 and 14. The Swedish Web-based QR questionnaire. 2. Attitude use app	1. Postoperative recovery showed improvement (significantly lower SwQoR score): On day 7: 69% (IG) vs 57% (CG) (P=0.001), (mean (SD) 28.23 (29.97) vs 34.87 (30.68), P<0.001). On day 14 postoperative recovery was 70% (IG) vs. 64% (CG) (P=0.06), (20.12(26.19) vs 21.90(22.40), P<0.002). 2. Positive attitudes patients feel valued. A RAPP has a reminders alert, but 30% of participants did not fill it out.
2	Schulz et al. (2020)/ Brazil (31)	RCT	Post-operative patients. Hospital	22 Age: Mean(SD): 69.2±7.4 (60–86)*	21 Age: Mean (SD): 69.±8 .4	All OS phone calls five times: Day (D): D4, D8, D12, D18, and	Regular consultations in hospital, three	Brazilian HCAIs: SSI Wound assessment and feedback: Nurses monitor	4	5 for IG, 3 For CG	1. Effectiveness of phone call reducing "delayed surgical	1. There was a difference characteristics on day 15 (p = 0.03). The recovery time IG reduced compared to CG (p = 0.046). Causative factors in both groups: "pain" variables (p =

				(60–90)*	D25 post-operative.	times: (D2, D15, D30)	based on a "Delayed Surgical Recovery" nursing diagnosis.			recovery" 2. Cost of the phone calls 3. experienced use of an app	0.041), and "post-operative expectation" in IG (p = 0.023). 2. Telecare was cheaper. The total cost was R$ 363.44 ($114.8). Easy to use, a high level of compliance with a sense of continuity of care.
3	Rea et.al.(2018)/United States (32)	Pilot (NRS)	Nurses (RN) Hospital	14	Nil	All OS: cloud software: Documented CAUTI prevention (No Mad CAUTI survey)	Nil	English HCAIs: SSI Sign-in accounts for access, demographic data (anonymous), Compliance with CAUTI Prevention.	15	2 weeks before and 10 weeks after IG	1. Nursing quality improvement (CAUTI rates). 2. Compliance CAUTI Prevention and reduction. 3. Satisfaction and efficiency	1. No significant CAUTI rates (pre and post-test) (P=0.668; P=0.722). 2. Nursing practice: provision of chlorhexidine (P=0.003). 3. The participants rated: technology value (P=0.004), satisfaction (P=0.004), and speed of the method to share the data (P=0.001). Time to share datA (P=0.045). Technology methods, savings in human resources, time, and costs can be estimated at $5257.
4	Saffari et al.(2015)/Iran\ (33)	NRS	Nurses (ICU) Hospital	32 Age: Mean 43.3 ± 9.6 years) Sex: M (69%)	Nil	All OS: 45 shot message services (SMS). Each message of 15 to 25 words 9 and 11 am on weekdays	Nil	Not mentioned language. HCAIs: knowledge, attitude, and Practice (KAP) using guidelines the US CDC and World Health Organization	8	2 weeks after intervention	1. KAP HCAIs. 2. Participant satisfaction.	1. KAP scores increased: knowledge 17%, attitude 3%, and practice 9%. The lowest change in the attitude domain (p=0,01 versus p<.0,001). 2. Intervention satisfaction: 72% good alternative for training, 6% not appropriate, 22% as an excellent educational strategy.
The lead author was not a nurse											
5	Aldaz et al. (2015)/ United States (37)	Pilot (NRS)	HCW: nurses, physicians Hospital & Clinic	39 Divide: 1.Interview (n=16): (14 nurses, 2 physicians). 2. Assess (n=7): (5 nurses and 2 physicians. 3. Pilot study of 16 nurses	Nil	Android: Snap Cap system: Google Glass and mobile app: 1. Develop Snap Cap 2. Assessment eligibility. 3. lab-based pilot study.	Nil	English HCAIs: SSI 1. Wound assessment and feedback: documentation and healing progress 2. SnapCap smartphone app flow: capture, tag, and transfer digital pictures to patient records.	52	4 (speech-to-text for wound annotation)	1. Development system. 2. Check user and feature preferences. 3. Comparison between SnapCap System and Epic Haiku.	1. Google glass and android mobile phone app. 2. Eligibility: a) SnapCap can identify patients' barcodes. b) Video voice: only 2/16 (12.5%) nurses successfully. c) Double Photo Blink: statistically acceptable (Z(13) = -3.606, p <0.001, r = 0.7). d) Zoom head tilt (p=0,058). e) Speech-to-Text Annotation: five nurses difficult their accents. 3. No difference between SnapCap and Epic Haiku (p=0.083) user-friendliness. Nurses lack familiarity. The poor network can cause the app to stop during transcription.
6	Orwoll et al. (2018)/ United States (39)	NRS	Nurses (children's nurses with indwelling central venous catheters) Hospital	200 (units higher rates of CLABSI: bone marrow transplant, hematology-oncology, general critical care)	109 (units comprised: neonatal intensive care, general medical/surgical transitional care)	Computer OS and mobile OS: CLABSI App: Access app and completed a self-assessment at the end of the clinical shift.	No access CLABSI App.	English. HCAIs: CLABSI App's contents: a) self-assessment, b) preventive care bundle audit tool, c) micro-learning: video demonstration) . and c) tracking CVC type and location.	52 Competitions one month each: Sept, June, July.	Nil	1. CLABSI rates (study vs 12 months before) 2. Self-reported compliance CLABSI (self vs audit) 3. gamification effectiveness 4. Cost development app and feedback	1. CLABSI rate: IG decreased 48% from 3.31 (29/8768) to 1.72 (17/9886); $\chi 2$ P= 0.03) vs CG 1.65 (19/7219) to 1.66 (13/7879) P=0.161. 2. Independent audits per line day had lower GI compared to CG at 0.053 (522/9886) versus 0.066 (520/7879), respectively (P< 0.01). No significant difference in compliance between independent audit and self-assessment. 3. The average number of nurses completing the CLABSI app was ten times higher during the contest month (P = 0.02). 4. The cost for the CLABSI app $60,000. 5. GAMEQI approach was developed to increase staff involvement broadly in the prevention of HCAIs.
7	Kerbaj et al. (2017)/ France (38)	NRS	HCW: physician, nurses, nursing assistants. And housekeeping personnel.	18 (2 physicians, 8 nurses, 5 nursing assistants, And 3 housekeeping personnel).	Nil	All OS: SMS 4 periods: Period 1: preintervention. Periods 2, 3, and 4 (2 phases each: Phase 1: receive SMS 28 days every Monday	Nil	Language: Nil HCAIs: practice: hand hygiene 1. Rooms have been equipped with a radiofrequency identification-based (RFID). 2. SMS:	52 Periods: 2, 3 (28 days) period 4 (21 days), no feedback	Nil	1. Effect of SMS feedback on HCW hand hygiene and compliance 2. Participants respons	1. A total of 15,723 HCW hand hygiene. Period 1 (preintervention): 8,973 (57.1%) and during the intervention (periods 2, 3, and 4) 6,750 (42.9%). The level of hand hygiene compliance in period 1 was 1.336 out of 15,723 (14.89%). compliance rate significantly to 1,559 from 6,750 (23.09%) (Pearson 2, 41,038; P < .001). SMS

					(period 2,3), 21 days in period 4. Phase 2: no feedback: 48 days		received 1 of 2 types (congratulatory or encouragement) every Monday morning.	(48 days)			encouraged increased compliance to hand hygiene. 2. Texting once a week is well-received, inexpensive, time-saving, and less intrusive, with no decaying effect in the study.
8	Pathak et al. (2015)/ India (34)	Exploratory study	Post-operative patients. Hospital	536 Age: mean 40 years (95% CI, 38–41 years). Sex: M 397 (75%)	Nil	All OS: phone call: Interview patient's surgical site according to CDC-P guidelines	Nil	Hindi HCAIs: SSI The study assistant will call after surgery and ask SSI surveillance questions.	4	4	1. SSI detected and monitoring. 2. Identification of mobile phone ownership and limitation	1. Follow-up SSI was 6.3% (n=34). 10 patients detected SSI by mobile phone. 2. Mobile phone follow-up for 380 patients (74.5%). 75% Cellular phone ownership (95% CI, 73-78%) and 25% of patients (n=133) used shared phones. 3. The phone call was feasible to use in a rural setting to resolve follow-up cases for SSI. Limitations of not using photos wound patients because they do not have a smartphone.
9	Schepe r et al. (2019)/ Nether lands (35)	Cohort study	Post-operative (joint arthroplasty) patients. Hospital	69 Age: median, range: 68 (33–90)	Nil	iOS and Android: WoundcareApp: Fills out questions and uploads a photo of the wound every day. a warning to contact the physician by pressing the button app.	Nil	Dutch HCAIs: SSI a) Introductory page. b) A short daily questionnaire on the patient's wound; redness, pain (visual analog score, VAS), wound leakage, fever and wound images. Reminder by email	4	Nil	1. Evaluate the ease and usability of the app (days 15 and 30). 2. Conformity of patient-reported outcome and doctor-reported outcome. 3. Technical problem.	1. on day 30 (37/53.6%)) were comparable to day 15 (31/44.9%) for ease of use (P=0.43) and perceived usefulness (P=0.40) 2. App sent alerts on phones to 29 patients (2.2%) of the 1317 days. 3. 33 patients (80%) showed concordance with the patient-reported and doctor-reported outcomes 3. lack of number of warnings (due to technical algorithm problems on the iOs version)
10	Castillo et al (2017)/ Canada (36)	Cohort study	Post-operative (Caesarean Section). Hospital	105 Age: Mean 30 (range 20-44) years)	Nil	All OS: how2trak app: Upload photos of their incisions on days 3, 7, 10, and 30 and will be asked about signs and symptoms of infection.	Nil	English HCAIs: SSI Demographics, health history, and tools from NNIS and SS1 CDC scale. Feature uploading incision photos. Reminders or follow-up calls	20	Days 3, 7, 10, and 30	1. feasibility use mobile phone technology 2. Estimate the rate of SSIs.	1. Mobile app for SSI showed patient satisfaction and was helpful to study. Add multilingual in the app, and information might affect (demographics, socioeconomic/educational)—low cost for operator training and maintenance. 2. 45% of patients (47/105) uploaded photos, SSI was detected from photos at day ten postpartum, SSI rate was 2.3% among patients who uploaded photos and 0.9% among all participants.
11	Olaoye et al. (2020)/ Africa (40)	Cross-Sectional	Patients and HCW Hospital	85 (47 patients, 38 HCW) (4 doctors, 18 nurses, 6 pharmacists, and 10 other HCW). Most age: 18-25 years (25 participants)	Nil	Computer OS and mobile OS: CwPAMS App: Infection management: antimicrobials appropriate	Nil	English HCAIs: AMR Information App, Userguide, listed national and international guidelines: antimicrobial stewardship, infection prevention.	24	Nil	1. Development and implementation 2. assessing patient and HCW perspectives on the use of the app	1. Development app in 4 countries, 66.1% open section National Prescribing Guidelines. 2. Patient Response: 71.4% have no problem with health professionals used app 3. HCW: App access used on mobile phones (28.9%), tablets, and computers (7.9% each). CwPAMS Application users: physicians (100%), pharmacists (66.7%) and nurses (33.3%). 79% agree that the app is easy to access. The patients' concern is that mobile phone apps can distract HCW.

*__Note:__ IG: Interventions group; CG: Control group; OS: Operating System; RCT: Randomized Controlled Trials; NRS: Non-randomized controlled study; NINS: Nosocomial infections surveillance; CDC: Centers for Disease Control and Prevention; SSI: surgical site infection; CAUTI: Catheter-associated Urinary Tract Infections CLABSI: Central Line-associated Bloodstream Infection; AMR: Anti-Microbial Resistance

Risk of bias and study quality assessment

The risk of bias (RoB 2) for the RCT included two studies that assessed some concerns due to missing outcome data (30) and deviations from the intended interventions (31). Concerning the risk of bias for NRS using ROBIN: Two studies were rated as moderate (32,38), and two

studies were rated as serious regarding bias in the domain of the measurement of outcomes (39) and confounding aspects (37). Only one study rated as low risk of bias (33).

The NHLBI tool with 14 study quality criteria showed: two studies as "fair" (10/14, 71%) and two studies as "poor" (5-7/14, <50%) (Figure 2).

Nurse involved as lead author

Of the 11 studies, there were four studies (29%) by research nurses as the first authors to contribute intellectually: using the cloud-based software technology system of Qualaris (32), or develop mobile app post-operative: RAPP app assess SSI (30).

One study developed the world's most commonly used mobile phone "telecare" to assess SSI by nurses (31). One study used SMS to increase knowledge, attitude, and practice nurses of prevention HCAIs (39).

Medical doctors developed five studies: one study focused on nurses, one study for HCW, and three studies for patients (34–36,38,39). Two other studies, a study was developed by engineering for nurses in assessing patient wounds (37), and a study by pharmacy, developed an application related to Antimicrobial Stewardship for HCW (CwPAMS App) (40).

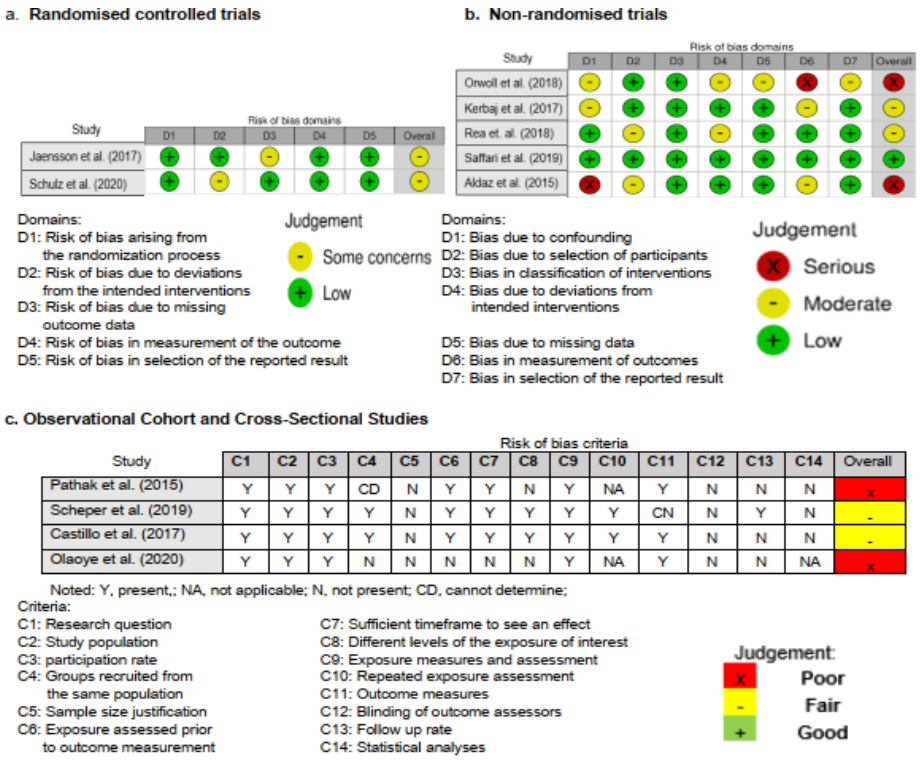

Figure 2. Quality Assessment of a. Randomized controlled trials using RoB 2.0, b. Non-randomized trials using ROBIN from the Cochrane Risk of Bias Assessment Tool, and c. Observational Cohort and Cross-Sectional Studies using National Heart, Lung, and Blood Institute (NHLBI).

Impact of using mobile-based applications on the prevention and reduction of HCAI

Two NRS studies showed: the SMS intervention increased 17% in knowledge, 3% in attitudes, and 9% in practice knowledge (p<.0.001) (33). In addition, incorporating hardware (a radio frequency identification system) and sending SMS encouragement showed a significant increase

in handwashing compliance rate (p< .001) (38).

Six studies revealed that app-based interventions, with the phone call, can significantly detect SSI (30,31,34–37). The SSI rate was 2.3% in patients who uploaded photos and 0.9% among all participants post-cesarean section (36). The telecare-based intervention detected SSI in 10 patients from a total follow-up of 6.3% (n=34) (34).

In the RCT study of Jaensson et al. (2017), the intervention group (RAPP app) showed a decrease in post-operative recovery time on day 7 (p=0.001) and day 14 (p=0.02) (36) compared to the control group with standard care. In line with the RCT study of Schulz et al. (2020), the telecare-based intervention group experienced a decrease in recovery time compared to the control group (p = 0.046) (37).

Three studies each evaluated the rate of CLABSI, CAUTI, and prevention of AMR. The result CLABSI app for nurses showed a significant decrease in the level of CLABSI by 48% (p= 0.03) compared to the control group that did not change (39). The study by Rea et al. (2018) developed cloud-based software to observe CAUTI prevention practices by nurses and document them compared to paper-based documentation, and the results showed no significant level of CAUTI (pre and post-test) (p=0.668; p=0.722). However, it was effective in the data sharing method (P=0.001) (32). Among the developmental and cross-sectional studies, Olaoye et al. (2020) designed the Commonwealth Partnerships for Antimicrobial Stewardship (CwPAMS Application) for HCW, usage app by doctors (100%), pharmacists (66.7%), and nurses (33.3%). As many as 79.0% agree that this application is easy to access and learn (40).

Feature app overview

Eleven studies identified features and compared their applications. Several features to assess the HCAI SS1 are assessing the patient's recovery and wound, a reminder feature, and the option to be contacted by the surgical nurse (30), and there is a warning if the score is above the threshold, with an offer to fill in the nearest health service contact (35,36). Phone calls by nurses are monitored for 30 days in post-operative patients and referred if there are indications of SS1 (31,34). Some studies use hardware such as Google Glass and a mobile phone app to upload wound photos and transfer them to patient medical records (37). Furthermore, there is the use of other hardware: a radiofrequency identification-based (RFID) and SMS to assess handwashing compliance of health workers (38). An SMS application is also used to help nurses improve knowledge, attitude, and practice (KAP) (33).

Three studies describe reporting features for reducing HCAI levels: using CAUTI and CLABSI. CAUTI is based on cloud software (32). CLABSI app features assessment, microlearning, and gamification to motivate nurse involvement (39). One study gives information on AMR prevention in a list, and documents can be accessed via mobile phones and computers (40).

Participant acceptance and response

Ten studies reported participants' acceptance, engagement, and satisfaction using the app (30–33,35–40). Participants' convenience (p=0.43) and perceived usefulness (p=0.40) (35), positive attitude, respect, safety consultation with nurses (30), Telecare, and SMS received if not too often (38). Ease and acceptance are not significant because nurses are less familiar.

Three studies reported satisfaction with using cloud-based apps (p=0.004) (32), 72% considered SMS as a good alternative (33), post-discharge satisfaction increased in patient participation and HCW (36). Reasons for participants to stop using the application included: not working (n= 1), no reminder (n= 2), patient forgetting (n= 6) (35). In contrast to Orwoll et al.'s (2018) study, positive feedback on research results further developed the GAMEQI approach for broad staff involvement in HCAI prevention (39).

Mobile applications issue

All studies describe the problems encountered during the study period related to the app and the participants' goals and concerns. Six studies describe the obstacles to follow-up even though there is a reminder system, lost data management (30), technical algorithm problems (35), and respondent data protection (32). Additional features are needed, for example, with automatic focus, stable connection stability (37), application updates (40), and the suitability of the app for the purpose, since SMS is only capable of simple theoretical messaging (33). Six studies identified participants' goals and concerns, including: worried that mobile phone apps distract HCWs and that HCW busyness reduces study engagement (40). The target participants related to the number of participants need to be adequate (31), individual characteristics, demographics, culture, literacy, the convenience of using the app, and user education (34,36,39), with strategies to prevent a decrease in motivation after the study (38).

Cost-effectiveness and cost-saving

Application development and operational costs (31,32,35,36,39) identified: a wound care app costs around 30,000 euros less because it is equivalent to 1 patient undergoing post-operative wound revision (35). CLABSI reduction in savings of more than $1 million (39). The cost of SMS is cheaper and more straightforward (33,38). Five times phone calls for 22 participants is R$ 363.44 ($114.8) (31). Application of cloud-based mobile phones compared to paper-based (32) savings are estimated at $5257, saving human resources and time. In line with Castillo et al., the app saves time and real-time maintenance and training costs. Challenges include access to patients and the need to coordinate health resources (36).

Discussion

This systematic review presents evidence that mobile phones can be used to support the prevention of HCAI. Most are performed by non-nurse professions (34–40). The involvement of nurses as leaders in the development of digital technology is still neglected because the ability of nurses to communicate ideas in daily practice is still limited (41,42), and low nurse informatics competence is associated with less time and pressure in service (43,44). Some of the constraints indicated the influences of nurse involvement experience before, perceived lack of facilitators, and future perspectives on digital (45).

The findings in this review are that nurses, as the first authors contributed intellectually to developing a mobile app, telecare, and SMS applications to improve prevention and HCAIs, both targeting patient users and nurses themselves (30–33). Only four studies focused on nurses. The majority focused on HCW: doctors, pharmacists, nursing assistants, health personnel, and nurses as important key services in proportion to the number and intensity of patient contact (46). (37,38,40). None of the studies was directed at nursing students. The reason may be because nursing students are limited by the

interaction of clinical practice time with dual roles as students and clinical internships (47,48). However, Jun et al. (2016) showed an increasingly positive trend in the quantity of digital technology involving the nursing profession in the practice or education driven by technological advances, organizational complexity, and outcomes (55).

This review of studies demonstrated the practical impact of interventions using a mobile phone app compared to standard care on the incidence of SSI (31), improving recovery (30), and decreasing CLABSI rates (39). The intervention periods were 14 days, 30 days, and one year. The results of the measurement study (pre-post) of one group showed that the use of the app intervention was effective, except in reducing CAUTI rates (pre and post-test), but showed an increase in Nursing prevention HCAI practice (32). In this review, there were no studies for HCAIs: VAP in the 2015-2021 range. It may be constrained by the location of the study, as reported by Jalali et al. (2018) that a cell phone-free zone is needed in areas of high risk of threatening safety, such as intensive care units (ICU), operating rooms, and critical care units (50). The findings in this systematic review can be used as the basis for a further description of the results of using apps in a clinical setting to complement the scoping review study of Bentvelsen et al. (2021) regarding eHealth for HCAIs. The study specifically reviewed the availability, functionality, and quality of HCAIs apps searched in stores rather than from journal databases and did not explain the effectiveness of user involvement in clinical settings (13).

Based on the included studies, there are differences in in-app feature content from simple to complex forms. In this review, the terms of use of simple to complex app according to the perception of ease from the aspects included: interface element design, mobile phone characteristics, physical characteristics, feedback, operation design, screen display, and connectivity (51). The study of Guo et al. (2015) mentioned mobile-based content for simple items containing reference readings, quizzes, and simple knowledge tests. But they have a low level of influence (52). Another study explains that adding a combination of content features increases user engagement and motivation but can increase the complexity of the computing system (28,53).

In this review, most respondents reported positive attitudes including they felt cared for by nurses and were accessible and satisfied in using the application (30–33,35–40). One study reported being dissatisfied with app use due to lack of familiarity (37). This result is also declared in a meta-analysis study that applying unfamiliarity technology can affect user satisfaction (54). There is a need to consider intervention plans and provide clear instructions on using these technologies (43).

Despite the obstacles found from this review, preventive measures and solutions to overcome the barriers need to be established to improve the app's quality, effectiveness, and security (11). This finding is consistent with the study by Ehrler (2013), which offered app implementation solutions in clinics, including stable connection, consideration of data integration into patient clinical systems, security and managed data storage, and app design using indexicality principles (18). Other recommendations are installing firewalls for hardware and software, updating applications by improving patient device safety, and mobile phone hygiene (41,50,55,56). However, these solutions are also influenced by hospital organizational complexities, such as information technology development,

specialization, government regulations, and patient-centered care (41,55,57).

This review identified that app development costs depend on the app's complexity, demographics, and operations (31,32,35,36,39). Overall, the advantages of implementing this app can be substantial cost savings, time-saving, real-time, with minimal operator training. These results are consistent with Iribarren et al. (2017), who reported that mobile health has proven beneficial and cost-effective in 29 studies. However, there are differences in economic reporting that are less comprehensive (58). It is essential to know the app's cost-effectiveness reporting to identify situational factors such as health conditions, support research planning, decision-making, and determine large-scale implementation models (59,60).

Study limitations

First, we limited publications in English, and the study quality assessment results were moderate to high, with only one study as a low-risk bias. The majority of the studies did not have a control group. The sample size and proportion of follow-up were small, while not blinded in providing intervention and data analysis. Second, the study populations are heterogeneous, so the effectiveness of using a mobile phone app cannot be intensely evaluated. Third, the search results did not find any research studies for preventing HCAIs: VAP nor research involving nursing students despite using various synonym keywords. We have attempted in response to these limitations to do some extensive searches using another source, namely Google Scholar.

Recommendations for research, practice, and policy

This systematic review revealed a lack of number and quality studies related to HCAIs focusing on nurse involvement in care settings. In addition, nursing students, especially baccalaureates, need to be involved in research to prevent HCAIs in service settings that will benefit nursing practice and education. Potential studies to develop design features such as real-time interactive systems, gamification, or save pictures or share buttons of participants' results from increasing motivation and interaction. The results of this review can help stakeholders consider the implementation of a large-scale and sustainable mobile phone app, especially in terms of the cost-effectiveness of implementation and their impact.

Conclusion

This systematic literature shows that app-based mobile phones have involved nurses as the first author in the study, participants, or intervention providers to patient-participants. We found no studies involving nursing students. The participants' responses were accepted and satisfied with getting the mobile phone app intervention, but one was also influenced by familiarity with technology. The findings of our review cannot be generalized to the effectiveness of mobile apps compared to standard care due to the limited amount of evidence and quality of studies. However, several studies have shown mobile phone apps can increase knowledge, attitude, and practice, reduce SSI and CLABSI rates and decrease CAUTI rates. We highlight the need to anticipate some of the problems encountered in implementing a mobile phone app. There is a potential for large-scale applications due to the substantial cost savings for HCAIs.

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