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Review

Should automated electronic hand-hygiene monitoring systems be implemented in routine patient care? Systematic review and appraisal with Medical Research Council Framework for Complex Interventions

D. Gould^a, C. Hawker^b, N. Drey^c, E. Purssell^{d,*}

^aIndependent Consultant, London, UK

^bSchool of Healthcare Sciences, Cardiff University, Cardiff, UK

^cSchool of Health & Psychological Sciences, Department of Nursing, City University, London, UK

^dFaculty of Health, Medicine and Social Care, School of Nursing and Midwifery, Anglia Ruskin University, Chelmsford, UK

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SUMMARY

Manual hand-hygiene audit is time-consuming, labour-intensive and inaccurate. Automated hand-hygiene monitoring systems (AHHMSs) offer advantages (generation of standardized data, avoidance of the Hawthorne effect). World Health Organization Guidelines for Hand Hygiene published in 2009 suggest that AHHMSs are a possible alternative. The objective of this review was to assess the current state of the literature for AHHMSs and offer recommendations for use in real-world settings. This was a systematic literature review, and publications included were from the time that PubMed commenced until 19th November 2023. Forty-three publications met the criteria. Using the Medical Research Council's Framework for Developing and Evaluating Complex Interventions, two were categorized as intervention development studies. Thirty-nine were evaluations. Two described implementation in real-world settings. Most were small scale and short duration. AHHMSs in conjunction with additional intervention (visual or auditory cue, performance feedback) could increase hand hygiene compliance in the short term. Impact on infection rates was difficult to determine. In the few publications where costs and resources were considered, time devoted to improving hand hygiene compliance increased when an AHHMS was in use. Health workers' opinions about AHHMSs were mixed. In conclusion, at present too little is known about the longer-term advantages of AHHMSs to recommend uptake in routine patient care. Until more longer-term accounts of implementation (over 12 months) become available, efforts should be made to improve direct observation of hand hygiene compliance to improve its accuracy and credibility. The Medical Research Council Framework could be used to categorize other complex interventions involving use of technology to prevent infection to help establish readiness for implementation.

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* Corresponding author. Address: Anglia Ruskin University, Bishop Hall Lane, Chelmsford, Essex, CM1 1SQ, UK. Tel.: +44 7782 374217. E-mail address: edward.purssell@aru.ac.uk (E. Purssell).

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Introduction

Hand hygiene is essential to prevent transmission of nosocomial and other pathogens [1] and is audited in many countries as part of quality assurance [2]. Traditionally, direct observation with manual documentation has been regarded as the 'gold standard' [3] but findings lack validity through selection bias [4–6], Hawthorne effect [7] (increased hand hygiene compliance when health workers are aware of being watched) [8] and poor quality-control [9]. Automated hand hygiene monitoring systems (AHHMSs) generate much larger volumes of standardized data continuously while avoiding selection and sampling bias [5,10,11]. World Health Organization (WHO) guidelines dating from 2009 [12] suggested that AHHMSs might provide valuable information about hand hygiene behaviour but cautioned need for 'real world' experience before recommending use in routine patient care. Fifteen years later in its directions for future research, the Alcohol-Based Handrub (ABHR) Taskforce in Geneva, Switzerland called for further research on the role of AHHMSs but did not offer recommendations for use in real-world settings [13].

Systematic reviews have since synthesized information on the technology [14], impact of using an AHHMS on hand hygiene compliance [15–17] and accuracy [18] but there is still a dearth of information to help decide whether routine use would benefit patients, clinicians, managers and infection prevention teams during routine care. This is an important gap in knowledge as the inflated rates of hand-hygiene compliance commonly generated through time-consuming manual audit are inaccurate, mislead patients and managers, raise ethical issues surrounding data collection and place reliance on information obtained through flawed methodologies [7]. Conversely, overly pessimistic rates could cause anxiety resulting in unnecessary intervention and waste of valuable resources. Such information is much needed as use of AHHMSs is being promoted by patient organizations [19] and benefits of AHHMSs compared with other forms of hand hygiene monitoring are discussed in recent guidelines issued by the Society for Healthcare Epidemiology of America (SHEA) [20]. Even if beneficial however, there are hurdles to implementation. Technology uptake in relation to infection prevention is slow and nurses and managers report a need for more information about feasibility of implementation as well as evidence of effectiveness [21]. These criteria are included in the Medical Research Council's (MRC's) criteria for complex interventions [22]. Interventions intended to enhance hand hygiene compliance meet MRC criteria [22] as they are usually multifaceted, multi-dimensional and challenging to implement [22,23].

We undertook a systematic review of initiatives in which AHHMSs had been introduced in real-world settings and categorized the interventions they described according to phase of study (intervention development, feasibility, evaluation or impact following implementation) as outlined in the updated MRC Framework for Developing and Evaluating Complex Interventions [22]. We addressed the six core questions posed by the MRC to appraise suitability of AHHMSs in patient care.

Methods

Systematic literature review

Searches were undertaken in PubMed from the time of its commencement until 19th November 2023. Search terms were: ("hand hygiene"[MeSH Terms] OR ("hand"[All Fields] AND "hygiene"[All Fields]) OR "hand hygiene"[All Fields]) AND ("electronic"[All Fields] OR "electronically"[All Fields] OR "electronics"[MeSH Terms] OR "electronics"[All Fields] OR "electronic"[All Fields]). Additional search strategies involved identifying potentially eligible papers in personal collections held by the research team and hand-searching high-yield journals. Reference lists of all retrieved publications were hand-searched. Publications eligible for inclusion were those focusing on AHHMSs as potential clinical tools. We excluded publications where remote video observation was undertaken. As this is an evolving area of enquiry, we included studies adopting any methodological approach: uncontrolled before and after studies, interrupted time series studies, non-randomized trials and randomized controlled trials. Qualitative studies were included where stakeholders reported opinions about clinical experience with AHHMSs. Exclusion criteria are shown in Table 1. Narrative synthesis [24] was undertaken to describe, summarize and explain eligible studies. The review was not registered and there is no publicly available protocol.

Applying core questions asked by the MRC's Framework for Developing and Evaluating Complex Interventions

The MRC in the UK has recently updated its guidance for developing and evaluating complex interventions. In an earlier iteration [25], attention focused on whether the intervention achieved its intended outcome. The updated framework [22] addresses wider issues in response to advances in research and

Table 1
Exclusion criteria

Publications were excluded:
Where data collection involved use of an AHHMS without discussing how it was introduced or employed
Where an AHHMS already in place was used to measure trends in hand hygiene behaviour over time (e.g., before, during and after the COVID-19 pandemic) without discussing introduction
Where the AHHMS was used to address a specific methodological issue (e.g., to assess the Hawthorne effect)
Where health workers were asked opinions about acceptability in hypothetical terms without experience of a specific AHHMS
If they were validation studies in laboratory and simulated settings
If they were validation studies in clinical settings where AHHMS performance was compared with hand hygiene data collected by another audit method without discussion of introduction

AHHMS, automated hand-hygiene monitoring system.

Table II

Phases and core questions asked by the Medical Council's Framework for Developing and Evaluating Complex Interventions [22]

Phases of complex intervention (not necessarily sequential)	At each phase, six core elements should be considered
Development or identification of an intervention	How does the intervention interact with the context?
Assessment of feasibility of the intervention and evaluation design	What programme theory underpins the research? (i.e., how does the intervention operate its effects?)
Evaluation of the intervention	Are stakeholders' perspectives included in the research?
Impactful implementation	Have key uncertainties been discussed? (Whether authors of quantitative studies have estimated error present in the data and the confidence they place in the findings) Are refinements to the intervention suggested? What are the consequences of the intervention for research outcomes and costs?

how findings are used (see Table II). Two members of the research team made decisions independently at all stages of the review with third party arbitration where discrepancy occurred.

Results

Systematic literature review

Initial searches located 2087 papers (see Figure 1). One hundred and twenty-one potentially eligible publications were identified. After screening, 55 were read in detail and of these 39 met the inclusion criteria (see Supplementary data). Two additional eligible publications were identified in personal collections [26,27], and two additional papers were identified through manual searching [28,29]. Short reports and conference abstracts were excluded because they contained insufficient detail for appraisal according to MRC recommendations.

Description of the studies

Publications originated from 17 different countries (see Supplementary data). In most publications, 'Radio Frequency' identification technology (RFID) was adopted. In half, a named AHHMS was employed [4,27–29,31–50]. In nine publications, intervention involved the use of an AHHMS developed by the research team [51–58]. In the remaining publications, the identity of the AHHMSs was not disclosed. The scopes of the initiatives varied. One AHHMS was tested with four beds in a single unit [38] while other interventions involved entire hospitals or hospital chains [34,36,47,59–61]. In most publications, use was restricted to one or two wards. Three publications described the introduction of an AHHMS in

outpatient departments [33,52,53]. In other publications not involving entire hospitals, interventions took place mainly in acute-care settings. Duration of intervention ranged from 145 h [57] to six years [59] but was typically less than a year. In one publication data collection continued over five years but occurred intermittently [28]. In seventeen publications [29,31,34–36,45–47,49,53,55,59,60,62–65] all health workers were monitored. In the remaining publications, nurses' and doctors' hand hygiene compliance was reported. Five publications reported non-randomised controlled trial (NCTs) [28,38,58,62,64], two reported randomized controlled trials [45,48], six reported interrupted time series studies [6,34,36,47,63,66] and five accounts were qualitative [27,39,51,67,68]. The remainder reported uncontrolled before and after studies, often with more than one intervention, introduced sequentially. The most frequently reported interventions combined introduction of an AHHMS with performance feedback, visual or auditory cue or vibration. In one publication [28] each of the four groups included in the NCT received a different set of interventions not described in detail.

In two publications, consumption of hand hygiene products was taken as the primary outcome measure [58,64]. A statistically significant increase in consumption was reported in one publication [58] but not in the other [64]. In the other publications, hand hygiene compliance was taken as the primary outcome. It increased in all but one publication [48]. In that study, length of time spent cleansing hands increased, however. Rate of hand hygiene compliance differed between initiatives at baseline and post-intervention between publications and for different clinical settings within the same organization in larger studies conducted across multiple sites [4,6,59,60,69]. Level of compliance varied between professional groups where this was reported [37,40,48]. Hand hygiene compliance usually returned to baseline levels once intervention discontinued. Infection rates were reported in nine publications [4,31,34,46,47,49,62–64]. Decrease was statistically significant in five publications [31,34,47,49,62].

Applying core questions from the MRC Framework for Complex Interventions

Two publications described development of an AHHMS [54,57]. Two were classified as implementation studies as they described the challenges encountered when using AHHMSs over time and attempts to overcome these challenges [59,60]. The others were classified as evaluation studies as they determined the effectiveness and/or utility of the intervention in a real-world setting but did not include details of the challenges encountered over time and attempts to overcome them (see Supplementary data). One publication [59] addressed five of the six core questions asked by the MRC [22]. Two publications [36,60,60] addressed four questions, two addressed three questions [39,48], 10 addressed two questions [27,29,34,35,37,45,51,63,67,68] and 16 [4,28,32,33,41,49,52–55,58,64] addressed one question only. In the remainder, none of the MRC's questions were addressed. In seven publications, authors considered interaction of the intervention with the study context [36,39,45,51,59,60,68]. Explanation of how the intervention was expected to exert its effects (programme theory) was provided in six publications [36,45,48,59,63,67]. Clinicians' perspectives were sought in 11 publications [27,32,36,39,48,51,59,60,67,68,70]. Nine of the quantitative

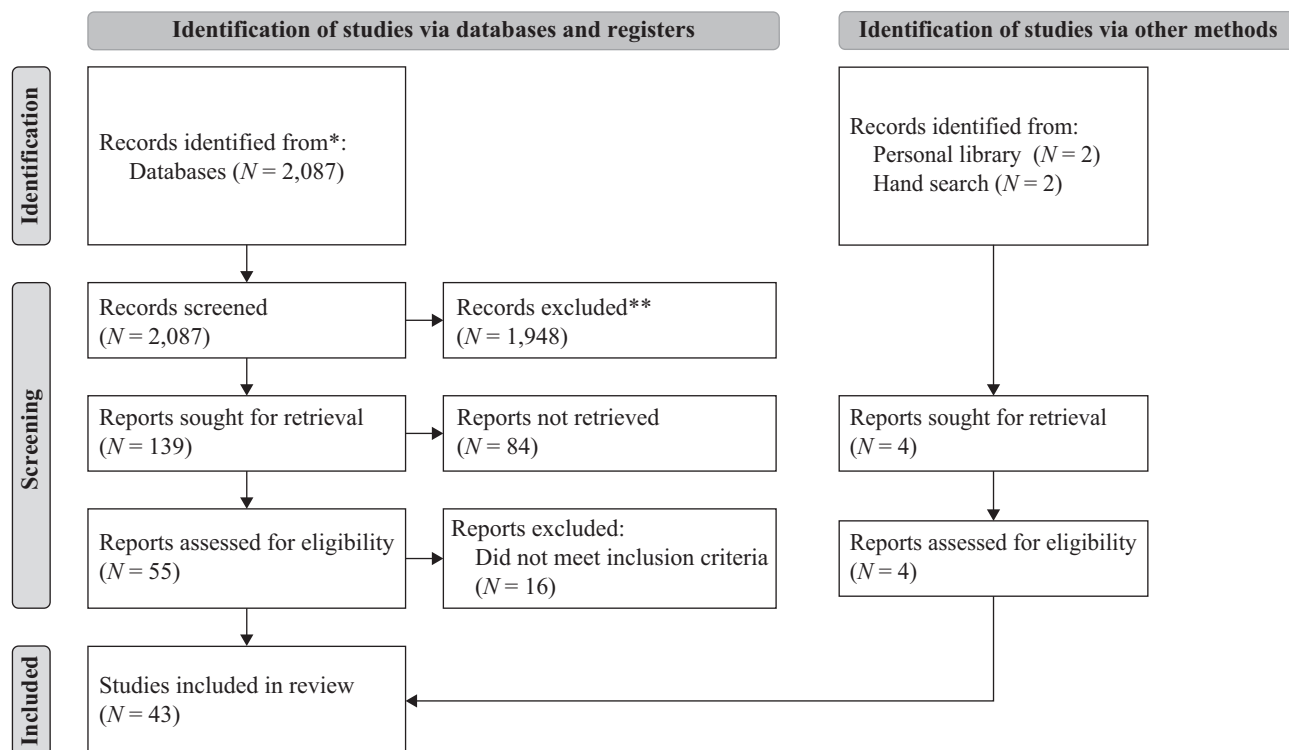


Figure 1. PRISMA 2020 flow diagram for new systematic reviews which included searches of databases, registers and other sources [30].

* Consider, if feasible to do so, reporting the number of records identified from each database or register searched (rather than the total number across all databases/register). ** If automation tools were used, indicate how many records were excluded by a human and how many were excluded by automation tools. From: Page et al. *BMJ* 2021;372:n71. For more information, visit <http://www.prisma-statement.org/>.

studies [35,36,55–57,59,60,67,70] reported clinicians' opinions. Information was obtained through interviews, questionnaires or focus groups. Two publications generated mostly positive comments [56,57], two were negative [35,70] and the others contained mixed views related mainly to system functionality or the intervention (e.g., acceptability of the cue, mode of delivering performance feedback). All qualitative publications reported clinicians' opinions. One reported predominantly positive findings [51], one mostly negative findings [27], and in the others opinions were expressed mainly in relation to system functionality [67,68] and the challenge of learning to work with the AHHMS [39]. Nevertheless, with a few notable exceptions where the AHHMS was deemed disappointing and use was discontinued [35,70], authors tended to be optimistic about using AHHMSs in clinical practice. Patients' reactions were mentioned in a single publication [70] and appeared to reflect impressions of the research team rather than to be based on empirical data. Nineteen publications suggested ways in which the intervention might be refined [4,33–36,39,48,49,53–55,57–60,64] but of these 10 commented exclusively on improvements to the technology [34,49,54–58,61,64,65]. Costs and resources were disclosed in five publications [37,52,58–60]. None of the research teams considered key uncertainties. Implementation studies [59,60] provided most information potentially useful to clinical teams, indicating messages for success. These were: sound leadership; involving clinicians, managers and patients in decisions; listening to concerns and finding practical solutions; and performance feedback delivered with constant, consistent

messaging. One provided detailed exemplars of challenges to implementation and how they had been resolved [59]. Of the evaluation studies, three [35,36,67] provided limited information about problems during implementation and attempts to overcome them.

Discussion

WHO guidelines dating from 2009 suggest that AHHMSs might provide valuable insight concerning hand hygiene behaviour but that more 'real-world' experience is needed before recommendations can be made for implementation in routine patient care [12]. In the intervening years, uptake of technology designed to improve infection prevention has been slow and attributed to the different types of information wanted by senior staff [21]. Doctors need to be convinced that technological solutions are underpinned by high-quality evidence. Nurses and managers are concerned about practicalities such as cost and acceptability to staff. We applied the MRC's criteria for developing and evaluating complex interventions [22] to publications describing the introduction and uptake of AHHMSs in real-world settings because they consider both quality of the evidence and factors likely to affect implementation. Overall, most initiatives eligible for inclusion in the review were small scale, of short duration and poorly controlled, reflecting hand hygiene interventions more generally [71].

Applying the MRC criteria for complex interventions [22], two publications described how the AHHMS was developed

[54,57]. Two further publications were classified as implementation studies [59,60]. These described challenges introducing and maintaining optimal use of AHHMSs over time and how problems were resolved. The detailed accounts they provide are likely to be of interest to clinicians and managers contemplating implementation of an AHHMS in routine patient care. For example, in the study described by Edmisten *et al.* [59], when the AHHMS was first introduced health workers expressed concern about long-term exposure to RFID communication-enabled badges and devices. These were resolved through interactive sessions and information from the Federal body responsible for safety. After the system had been in place for some time, limited access to monthly electronic data was reported to be problematic. The vendor developed a new dashboard with additional reporting options and until this was available, monthly feedback was maintained manually using spreadsheets.

Thirty-nine publications were classified as evaluations. These were primarily concerned with describing the effectiveness of an intervention involving use of an AHHMS in selected venues, often over a limited period. They addressed few or none of the six core issues considered by the MRC and which infection prevention teams are likely to regard as important. Few authors explained how the intervention interacted with the clinical environment or impacted on current expectations for hand hygiene compliance throughout the health provider organization. For example, although most authors stated that health workers were supposed to comply with the WHO's Five Moments for Hand Hygiene [72], inability of the AHHMS to document all five moments and meet these expectations was acknowledged in only one publication [63]. A logic model depicting how the intervention was intended to operate its effects was fully discussed in only six publications [36,45,48,59,63,67]. For most AHHMSs, the visual or auditory cue was an integral part of the system and there appeared to be a naive assumption that simple reminders would be sufficient to boost hand hygiene compliance indefinitely. Authors were concerned mainly with issues related to functionality of the technology. Examination of stakeholders' opinions of AHHMSs was simplistic and except for the implementation studies [59,60] took into account the views of clinicians only, ignoring service users, managers and infection prevention teams. Health workers' perceptions were explored in depth in four publications [27,35,67,68]. In these reports, clinicians complained that the automated system frequently indicated that hands should be cleansed when they considered it unnecessary. They invariably concluded that system error had occurred and that they had made the correct decision, not the system. Information on costs were under-reported except in the implementation studies [59,60]. These identified substantial increase in time devoted to hand hygiene when AHHMSs were used, not cost-saving.

Many of the supposed benefits of AHHMSs were not realised. Authors did not explain how the additional data generated were used to benefit patients or the organization and appeared to have made little attempt to use AHHMSs to overcome selection and sampling bias. Information relating to selection of venue was seldom revealed, an important omission as it is likely that systems were introduced in settings where staff were likely to have been highly motivated and performed well [73]. This effect is likely to have been especially marked in the four publications [55–57,67] where data were collected solely

from volunteers. Despite increasing interest in automated hand hygiene monitoring, ours appears to be the first review to appraise use of AHHMSs in real-world settings and to consider whether they can work, how they work and whether they are worthwhile [74]. As in earlier reviews [14,17,18], different types of technology were described. Findings were in line with those described by Srigley *et al.* [16]: initially introduction of an AHHMS accompanied by a cue or performance feedback could increase hand hygiene compliance but improvement was not usually sustained once the intervention was withdrawn. Hand hygiene compliance differed between organizations and between different clinical settings in the same organization, corroborating the findings of an earlier review describing interventions to increase hand hygiene compliance with and without automated monitoring [23]. Infection rates were documented in less than a quarter of publications and findings were inconsistent.

Most of the publications we reviewed presented early-phase studies with few messages to inform uptake of AHHMSs in routine patient care. More publications are required to describe use of AHHMSs longer term (over 12 months), challenges encountered and how they can be resolved. In the meantime, efforts should be made to establish more objective ways of auditing by direct observation to improve accuracy, standardization of data and increasing acceptability to health workers who are aware that audit findings lack validity [75,76]. Efforts should be made to improve data collection, beginning with re-consideration of its purpose. It may be better to audit less often but more rigorously with improved training and validation for those gathering and interpreting data. Recently updated guidance recommends limiting each audit session to 10–20 min or obtaining enough data to provide a reasonable estimate of adherence rates and conducting audit randomly on all shifts and working days [20]. The practicalities of this approach need to be established. At present, audit tends to be undertaken at times of when clinical areas are busy because auditors are available, and with high levels of clinical activity, it is possible to collect the necessary volume of data quickly. Auditing 'around the clock' would have cost implications through the need for increased manpower of the audit team and the longer time required to generate sufficient data when clinical activity is lower. There is also a risk that at less busy times, health workers would be more conscious of being observed, increasing the Hawthorne effect. Questions should be asked about the much-vaunted educational opportunities claimed for manual audit [3,73]. At present there is no evidence that health workers value having their hand hygiene practice corrected at the point of care or that this is the most effective approach. Patients' satisfaction with hand hygiene audit and further information on health workers' and managers' experiences merit additional research, especially when new approaches to manual audit are trialled. Finally, costs of manual audit should be estimated to enable comparison with electronic monitoring.

It is possible that some eligible publications were overlooked. Omissions were unlikely however, as members of the research team are familiar with the literature relating to hand hygiene audit. Some research studies may have been double-counted as different aspects of the same initiative (e.g., technology development, acceptability to health workers) appear to have been described in separate publications or the same initiative may have been reported at different points in

time as the work evolved. Our aim was to review publications containing sufficient description of system implementation to apply the MRC Framework [22] and to do so it was necessary to develop and apply a relatively large number of exclusion criteria. These were rigorously applied but it is possible that others auditing the review might question some of the decisions taken. Using the MRC Framework [22] to categorize publications according to phase of research and appraise readiness of the overall body of the literature was a strength however and the same approach could be used to determine phase of development of other complex interventions involving introduction of technology intended to prevent infection to assess readiness for implementation.

In conclusion, our review has demonstrated that the body of literature regarding AHHMSs has yet to move into questions of widespread effectiveness, cost-effectiveness, or equity to inform decision-making [77], does not yet permit judgements about the significance of heterogeneity and indirectness, and that additional contextual and qualitative information is needed [78].

Conflict of interest statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jhin.2024.03.012>.

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