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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

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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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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 ("electronical"[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 I. 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 I
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

AHMMS, automated hand-hygiene monitoring system.

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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

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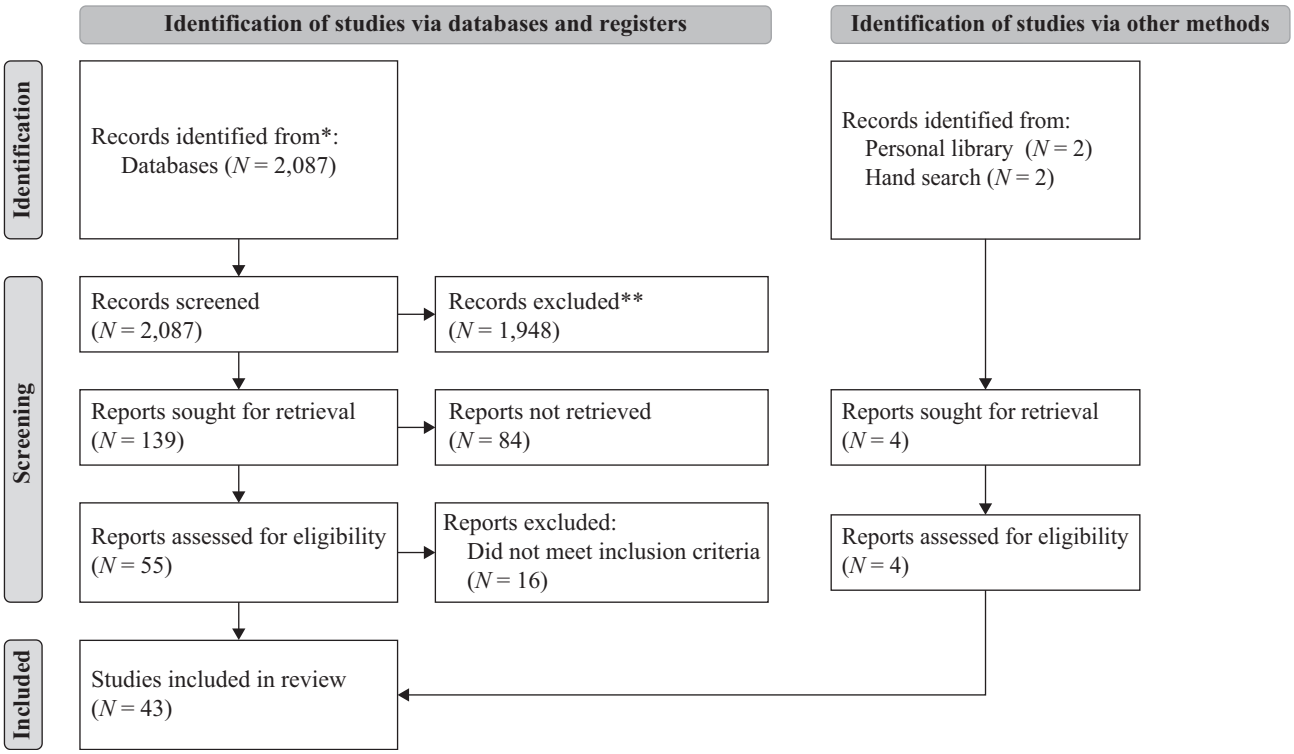

Figure 1. PRISMA 2020 flow diagram for new systematic reviews which included searches of databases, registers and other sources [30]. * Consider, if feasible to do so, reporting the number of records identified from each database or register searched (rather than the total number across all databases/registers). ** 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

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[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

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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

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References

[1] Pittet D, Allegranzi B, Sax H, Dharan S, Pessoa-Silva CL, Donaldson L, et al. Evidence-based model for hand transmission during patient care and the role of improved practices. Lancet Infect Dis 2006;6:641–52.

[2] Allegranzi B, Kilpatrick C, Sax H, Pittet D. 'My Five Moments': understanding a user-centred approach to hand hygiene improvement within a broader implementation strategy. BMJ Qual Saf 2022;31:259–62.

[3] Haas JP, Larson EL. Measurement of compliance with hand hygiene. J Hosp Infect 2007;66:6–14.

[4] Boyce JM. Electronic monitoring in combination with direct observation as a means to significantly improve hand hygiene compliance. Am J Infect Control 2017;45:528–35.

[5] Boyce JM, Cooper T, Yin J, Li F-Y, Arbogast JW. Challenges encountered and lessons learned during a trial of an electronic hand hygiene monitoring system. Am J Infect Control 2019;47:1443–8.

[6] Boyce JM, Laughman JA, Ader MH, Wagner PT, Parker AE, Arbogast JW. Impact of an automated hand hygiene monitoring system and additional promotional activities on hand hygiene performance rates and healthcare-associated infections. Infect Control Hosp Epidemiol 2019;40:741–7.

[7] Purssell E, Drey N, Chudleigh J, Creedon S, Gould DJ. The Hawthorne effect on adherence to hand hygiene in patient care. J Hosp Infect 2020;106:311–7.

[8] McCambridge J, Witton J, Elbourne DR. Systematic review of the Hawthorne effect: new concepts are needed to study research participation effects. J Clin Epidemiol 2014;67:267–77.

[9] Jeanes A, Coen PG, Gould DJ, Drey NS. Validity of hand hygiene compliance measurement by observation: a systematic review. Am J Infect Control 2019;47:313–22.

[10] Gould D, Lindström H, Purssell E, Wigglesworth N. Electronic hand hygiene monitoring: accuracy, impact on the Hawthorne effect and efficiency. J Infect Prev 2020;21:136–43.

[11] Masroor N, Doll M, Stevens M, Bearman G. Approaches to hand hygiene monitoring: From low to high technology approaches. Int J Infect Dis 2017;65:101–4.

[12] World Health Organization, WHO Patient Safety. WHO guidelines on hand hygiene in health care. 2009. p. 262.

[13] Tartari E, Bellissimo-Rodrigues F, Pires D, Fankhauser C, Lotfinejad N, Saito H, et al. Updates and future directions regarding hand hygiene in the healthcare setting: insights from the 3rd ICPIC alcohol-based handrub (ABHR) task force. Antimicrob Resist Infect Control 2024;13:26.

[14] Wang C, Jiang W, Yang K, Yu D, Newn J, Sarsenbayeva Z, et al. Electronic monitoring systems for hand hygiene: systematic review of technology. J Med Internet Res 2021;23:e27880.

[15] Lin T-Y, Lin C-T, Chen K-M, Hsu H-F. Information technology on hand hygiene compliance among health care professionals: a systematic review and meta-analysis. J Nurs Manag 2021;29:1857–68.

[16] Srigley JA, Furness CD, Gardam M. Interventions to improve patient hand hygiene: a systematic review. J Hosp Infect 2016;94:23–9.

[17] Zhang Y, Chen X, Lao Y, Qiu X, Liu K, Zhuang Y, et al. Effects of the implementation of intelligent technology for hand hygiene in hospitals: systematic review and meta-analysis. J Med Internet Res 2023;25:e37249.

[18] Ward MA, Schweizer ML, Polgreen PM, Gupta K, Reisinger HS, Perencevich EN. Automated and electronically assisted hand hygiene monitoring systems: A systematic review. Am J Infect Control 2014;42:472–8.

[19] The Leapfrog Group. Search Leapfrog's hospital and surgery center ratings | Hospital and Surgery Center Ratings | Leapfrog Group, n.d. Available at: https://ratings.leapfroggroup.org/ [last accessed February 2024].

[20] Glowicz JB, Landon E, Sickbert-Bennett EE, Aiello AE, deKay K, Hoffmann KK, et al. SHEA/IDSA/APIC Practice Recommendation: Strategies to prevent healthcare-associated infections through hand hygiene: 2022 Update. Infect Control Hosp Epidemiol 2023;44:355–76.

[21] Kyratsis Y, Ahmad R, Holmes A. Technology adoption and implementation in organisations: comparative case studies of 12 English NHS Trusts. BMJ Open 2012;2:e000872.

[22] Skivington K, Matthews L, Simpson SA, Craig P, Baird J, Blazeby JM, et al. A new framework for developing and evaluating complex interventions: update of Medical Research Council guidance. BMJ 2021:n2061.

[23] Drey N, Gould D, Purssell E, Chudleigh J, Moralejo D, Gallagher R, et al. Applying thematic synthesis to interpretation and commentary in epidemiological studies: identifying what contributes to successful interventions to promote hand hygiene in patient care. BMJ Qual Saf 2020;29:756–63.

[24] Popay J, Roberts H, Sowden A, Petticrew M, Arai L, Rodgers M, et al. Guidance on the conduct of narrative synthesis in systematic reviews: a product from the esrc methods programme. York: University of York; 2006.

[25] Craig P, Dieppe P, Macintyre S, Michie S, Nazareth I, Petticrew M. Developing and evaluating complex interventions: the new Medical Research Council guidance. BMJ 2008:a1655.

[26] Hayashi M, Fujiwara H, Koufuku T, Nakai I. [Introduction of a hand-hygiene automated monitoring system: accuracy in

monitoring hand hygiene compliance and its effect in promoting hand hygiene behaviour]. Kansenshogaku Zasshi 2016;90:803–8.
[27] Tarantini C, Brouqui P, Wilson R, Griffiths K, Patouraux P, Peretti-Watel P. Healthcare workers' attitudes towards hand-hygiene monitoring technology. J Hosp Infect 2019;102:413–8.
[28] Arbogast JW, Moore LD, DiGiorgio M, Robbins G, Clark TL, Thompson MF, et al. The impact of automated hand hygiene monitoring with and without complementary improvement strategies on performance rates. Infect Control Hosp Epidemiol 2023;44:638–42.
[29] Starrett WG, Arbogast JW, Parker AE, Wagner PT, Mahrer SE, Christian V, et al. The effect of a prospective intervention program with automated monitoring of hand hygiene performance in long-term and acute-care units at a Veterans Affairs medical center. Infect Control Hosp Epidemiol 2024;45:207–14.
[30] Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021:n71.
[31] Akkoc G, Soysal A, Gul F, Kepenekli Kadayifci E, Arslantas MK, Yakut N, et al. Reduction of nosocomial infections in the intensive care unit using an electronic hand hygiene compliance monitoring system. J Infect Dev Ctries 2021;15:1923–8.
[32] Al Salman JM, Hani S, De Marcellis-Warin N, Fatima Isa S. Effectiveness of an electronic hand hygiene monitoring system on healthcare workers' compliance to guidelines. J Infect Public Health 2015;8:117–26.
[33] Arai A, Tanabe M, Nakamura A, Yamasaki D, Muraki Y, Kaneko T, et al. Utility of electronic hand hygiene counting devices for measuring physicians' hand hygiene adherence applied to outpatient settings. Am J Infect Control 2016;44:1481–5.
[34] Banks M, Phillips AB. Evaluating the effect of automated hand hygiene technology on compliance and C. difficile rates in a long-term acute care hospital. Am J Infect Control 2021;49:727–32.
[35] Benudis A, Stone S, Sait AS, Mahoney I, Price LL, Moreno-Koehler A, et al. Pitfalls and unexpected benefits of an electronic hand hygiene monitoring system. Am J Infect Control 2019;47:1102–6.
[36] Conway LJ, Riley L, Saiman L, Cohen B, Alper P, Larson EL. Implementation and impact of an automated group monitoring and feedback system to promote hand hygiene among health care personnel. Jt Comm J Qual Patient Saf 2014;40:408–17.
[37] Fish L, Bopp D, Gregory D, Kerley KD, Gakhar S, Lavigne MC, et al. Hand hygiene feedback impacts compliance. Am J Infect Control 2021;49:907–11.
[38] Generoso JR, Casaroto E, Neto AS, Prado M, Gagliardi GM, de Menezes FG, et al. Comparison of two electronic hand hygiene systems using real-time feedback via wireless technology to improve hand hygiene compliance in an intensive care unit. Antimicrob Steward Healthc Epidemiol 2022;2:e127.
[39] Granqvist K, Ahlstrom L, Karlsson J, Lytsy B, Andersson AE. Learning to interact with new technology: Health care workers' experiences of using a monitoring system for assessing hand hygiene – a grounded theory study. Am J Infect Control 2022;50:651–6.
[40] Huang F, Boudjema S, Brouqui P. Three-year hand hygiene monitoring and impact of real-time reminders on compliance. J Hosp Infect 2021;117:111–6.
[41] Iversen A-M, Stangerup M, From-Hansen M, Hansen R, Sode LP, Kostadinov K, et al. Light-guided nudging and data-driven performance feedback improve hand hygiene compliance among nurses and doctors. Am J Infect Control 2021;49:733–9.
[42] Iversen A-M, Hansen MB, Kristensen B, Ellermann-Eriksen S. Clinical evaluation of an electronic hand hygiene monitoring system. Am J Infect Control 2023;51:376–9.
[43] Kelly JW, Blackhurst D, McAtee W, Steed C. Electronic hand hygiene monitoring as a tool for reducing health care–associated methicillin-resistant Staphylococcus aureus infection. Am J Infect Control 2016;44:956–7.
[44] Kwok YLA, Juergens CP, McLaws M-L. Automated hand hygiene auditing with and without an intervention. Am J Infect Control 2016;44:1475–80.
[45] Leis JA, Powis JE, McGeer A, Ricciuto DR, Agnihotri T, Coyle N, et al. Introduction of group electronic monitoring of hand hygiene on inpatient units: a multicenter cluster randomized quality improvement study. Clin Infect Dis 2020;71:e680–5.
[46] McCalla S, Reilly M, Thomas R, McSpedon-Rai D. An automated hand hygiene compliance system is associated with improved monitoring of hand hygiene. Am J Infect Control 2017;45:492–7.
[47] McCalla S, Reilly M, Thomas R, McSpedon-Rai D, McMahon LA, Palumbo M. An automated hand hygiene compliance system is associated with decreased rates of health care-associated infections. Am J Infect Control 2018;46:1381–6.
[48] Pires D, Gayet-Ageron A, Guitart C, Robert Y-A, Fankhauser C, Tartari E, et al. Effect of wearing a novel electronic wearable device on hand hygiene compliance among health care workers: a stepped-wedge cluster randomized clinical trial. JAMA Netw Open 2021;4:e2035331.
[49] Swoboda SM, Earsing K, Strauss K, Lane S, Lipsett PA. Isolation status and voice prompts improve hand hygiene. Am J Infect Control 2007;35:470–6.
[50] Zwicker P, Meng M, Friesecke S, Stein T, Herzog A, Herzer C, et al. An interactive feedback system for increasing hand antisepsis adherence in stationary intensive care. J Hosp Infect 2023;133:73–80.
[51] Blomgren P-O, Lytsy B, Hjelm K, Swenne CL. Healthcare workers' perceptions and acceptance of an electronic reminder system for hand hygiene. J Hosp Infect 2021;108:197–204.
[52] Geilleit R, Hen ZQ, Chong CY, Loh AP, Pang NL, Peterson GM, et al. Feasibility of a real-time hand hygiene notification machine learning system in outpatient clinics. J Hosp Infect 2018;100:183–9.
[53] Kato H, Takeda R, Ideno Y, Suzuki T, Sano K, Nakamura K. Physicians' compliance for hand hygiene in medical outpatient clinics: automated hand-hygiene monitoring with touch sensor and wireless internet. Am J Infect Control 2021;49:50–4.
[54] Kinsella G, Thomas AN, Taylor RJ. Electronic surveillance of wall-mounted soap and alcohol gel dispensers in an intensive care unit. J Hosp Infect 2007;66:34–9.
[55] Levchenko AI, Boscart VM, Fernie GR. Automated monitoring: a potential solution for achieving sustainable improvement in hand hygiene practices. Comput Inform Nurs 2014;32:397–403.
[56] Levchenko AI, Boscart VM, Fernie GR. The effect of automated monitoring and real-time prompting on nurses' hand hygiene performance. Comput Inform Nurs 2013;31:498–504.
[57] Levchenko AI, Boscart VM, Fernie GR. The feasibility of an automated monitoring system to improve nurses' hand hygiene. Int J Med Inform 2011;80:596–603.
[58] Radhakrishna K, Waghmare A, Ekstrand M, Raj T, Selvam S, Sreerama SM, et al. Real-time feedback for improving compliance to hand sanitization among healthcare workers in an open layout ICU using radiofrequency identification. J Med Syst 2015;39:68.
[59] Edmisten C, Hall C, Kernizan L, Korwek K, Preston A, Rhoades E, et al. Implementing an electronic hand hygiene monitoring system: lessons learned from community hospitals. Am J Infect Control 2017;45:860–5.
[60] McMullen K, Diesel G, Gibbs E, Viox A, Dietzler-Otte J, McIntire J, et al. Implementation of an electronic hand hygiene monitoring system: learnings on how to maximize the investment. Am J Infect Control 2023;51:847–51.
[61] Sahud AG, Bhanot N, Narasimhan S, Malka ES. Feasibility and effectiveness of an electronic hand hygiene feedback device targeted to improve rates of hand hygiene. J Hosp Infect 2012;82:271–3.
[62] Ellison RT, Barysauskas CM, Rundensteiner EA, Wang D, Barton B. A prospective controlled trial of an electronic hand hygiene reminder system. Open Forum Infect Dis 2015;2:ofv121.

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[63] Knepper BC, Miller AM, Young HL. Impact of an automated hand hygiene monitoring system combined with a performance improvement intervention on hospital-acquired infections. Infect Control Hosp Epidemiol 2020;41:931–7.
[64] Marra AR, D'Arco C, Bravim BDA, Martino MDV, Correa L, Silva CV, et al. Controlled trial measuring the effect of a feedback intervention on hand hygiene compliance in a step-down unit. Infect Control Hosp Epidemiol 2008;29:730–5.
[65] Morgan DJ, Pineles L, Shardell M, Young A, Ellingson K, Jernigan JA, et al. Automated hand hygiene count devices may better measure compliance than human observation. Am J Infect Control 2012;40:955–9.
[66] Zhong X, Wang D-L, Xiao L-H, Mo L-F, Wu Q-F, Chen Y-W, et al. Comparison of two electronic hand hygiene monitoring systems in promoting hand hygiene of healthcare workers in the intensive care unit. BMC Infect Dis 2021;21:50.
[67] Dyson J, Madeo M. Investigating the use of an electronic hand hygiene monitoring and prompt device: influence and acceptability. J Infect Prev 2017;18:278–87.
[68] Kelly D, Purssell E, Wigglesworth N, Gould D. Electronic hand hygiene monitoring systems can be well-tolerated by health workers: Findings of a qualitative study. J Infect Prev 2021; 22:246–51.
[69] Leis JA, Obaidallah M, Williams V, Muller MP, Powis JE, Johnstone J, et al. Validation and implementation of group electronic hand hygiene monitoring across twenty-four critical care units. Infect Control Hosp Epidemiol 2022;43:834–9.
[70] Levin PD, Razon R, Schwartz C, Avidan A, Sprung CL, Moses AE, et al. Obstacles to the successful introduction of an electronic hand hygiene monitoring system, a cohort observational study. Antimicrob Resist Infect Control 2019;8:43.
[71] Gould D, Creedon S, Jeanes A, Drey NS, Chudleigh J, Moralejo D. Impact of observing hand hygiene in practice and research: a methodological reconsideration. J Hosp Infect 2017;95:169–74.
[72] Sax H, Allegranzi B, Uçkay I, Larson E, Boyce J, Pittet D. 'My five moments for hand hygiene': a user-centred design approach to understand, train, monitor and report hand hygiene. J Hosp Infect 2007;67:9–21.
[73] Doll ME, Pierce JW. Electronic hand hygiene monitoring systems: Not worth the costs. Antimicrob Steward Healthc Epidemiol 2022;2:e126.
[74] Haynes B. Can it work? Does it work? Is it worth it? The testing of healthcare interventions is evolving. BMJ 1999;319:652–3.
[75] Cawthorne K-R, Cooke RPD. Healthcare workers' attitudes to how hand hygiene performance is currently monitored and assessed. J Hosp Infect 2020;105:705–9.
[76] Livorsi DJ, Goedken CC, Sauder M, Vander Weg MW, Perencevich EN, Reisinger HS. Evaluation of barriers to audit-and-feedback programs that used direct observation of hand hygiene compliance: a qualitative study. JAMA Netw Open 2018;1:e183344.
[77] Alonso-Coello P, Schünemann HJ, Moberg J, Brignardello-Petersen R, Akl EA, Davoli M, et al. GRADE Evidence to Decision (EtD) frameworks: a systematic and transparent approach to making well informed healthcare choices. 1: Introduction. BMJ 2016:i2016.
[78] Murad MH, Almasri J, Alsawas M, Farah W. Grading the quality of evidence in complex interventions: a guide for evidence-based practitioners. BMJ Evid Based Med 2017;22:20–2.

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