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Rinse, gel, and foam – is there any evidence for a difference in their effectiveness in preventing infections?

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Abstract

Background Following publication of the 2009 World Health Organizations Guidelines for Hand Hygiene in Health Care, a debate has emerged regarding the relative antimicrobial efficacy of the different formats (rinse, gel, foam) of ABHRs and their ability to contribute to reduction of healthcare-associated infections (HAIs).

Methods Data regarding the in-vivo antimicrobial efficacy of ABHRs and other factors that likely affect their effectiveness in reducing HAIs were reviewed, and a comprehensive review of studies that reported the effectiveness of each of the three ABHR formats to improve hand hygiene compliance and reduce HAIs was conducted.

Results The amount of rubbing time it takes for hands to feel dry (dry time) is the major driver of ABHR antimicrobial efficacy. ABHR format is not a major factor, and several studies found that rinse, gel, and foam ABHRs have comparable in-vivo antimicrobial efficacy. Other factors that likely impact the ability of ABHRs to reduce transmission of healthcare-associated pathogens and HAIs include ABHR formulation, the volume applied to hands, aesthetic characteristics, skin tolerance, acceptance by healthcare personnel, and hand hygiene compliance rates. When accompanied by complementary strategies, promoting the use of each of the three ABHR formats has been associated with improvements in hand hygiene compliance rates. A review of 67 studies failed to identify an ABHR format that was significantly more effective in yielding statistically significant reductions in transmission of healthcare-associated pathogens or HAIs.

Conclusions Current evidence is insufficient to definitively determine if one ABHR format is more effective in reducing transmission of healthcare-associated pathogens and HAIs. More rigorous studies such as multicenter randomized controlled trials comparing the different formats are needed to establish if one format is significantly more effective in reducing HAIs.

Keywords Alcohol-based hand rub, Rinse, Gel, Foam, Healthcare-associated infections, Effectiveness, Antimicrobial efficacy

Introduction

Alcohol-based hand rubs (ABHR) have been available for decades in several formats: liquid -also called rinse-, gel, and foam. Despite their availability for years, there is continued debate regarding the effectiveness of gel and foam products in reducing healthcare-associated infections (HAIs). Several publications may have contributed to concerns regarding their effectiveness [1–4]. For example, one early study that compared several gels to

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four rinses found that none of the ten gels met EN 1500 criteria for efficacy, while all four rinses did [1]. Another early study found that a gel failed EN 1500 efficacy criteria, perhaps due to the low concentration of alcohol (60% isopropanol) [2]. A 2008 controlled trial using a 62% ethanol ABHR gel failed to demonstrate a reduction in device-related infections and multidrug-resistant organism (MDRO) infections [3]. A number of issues have been proposed to explain the lack of apparent efficacy of the gel [5, 6]. A 2013 in vivo laboratory study reported that 1.1 ml of 70% ethanol gel and foam products did not meet U.S. FDA criteria for efficacy, and were inferior to 2 ml of an 85% ethanol ABHR gel [7]. Of note, the methods used were not those required by the FDA, and other studies have found that the 70% gel and foam products meet FDA efficacy standards [8, 9].

The text of the 2009 WHO Guidelines for Hand Hygiene in Health Care notes that rinse, gel and foam ABHRs are available for use in healthcare, and does not recommend one format over another. The 2022 Practice Recommendation: Strategies to Prevent HAIs Through Hand Hygiene published by the Society for Healthcare Epidemiology of America (SHEA), the Infectious Diseases Society of America (IDSA) and the Association for Professionals in Infection Control and Epidemiology (APIC) recommends use of either a liquid, gel, or foam ABHR with at least 60% alcohol [10].

In attempting to answer the question regarding the effectiveness of ABHRs in preventing HAIs, a current literature review failed to identify any controlled trial that compared the effectiveness of different ABHR formats and used the incidence density of HAIs as an outcome measure. In view of the lack of controlled trials to answer the question regarding the relative effectiveness of rinses, gels, and foams to reduce HAIs, the objective of this paper is two-fold: 1) to discuss factors affecting the in-vivo efficacy and effectiveness of the three ABHR formats in reducing HAIs, and 2) to present a literature review of hand hygiene studies that monitored the frequency of HAIs while using either a liquid, a gel, or a foam ABHR.

Methods used for literature review

A literature review to identify publications that included information regarding both hand hygiene and HAI rates was conducted by one of the authors (JMB). The PubMed and Google Scholar databases were searched for publications between 2000 and 2023. The following search terms used on the PubMed database included: hand hygiene + healthcare-associated infections; cross infection/prevention & control + hand hygiene + (healthcare-associated infections + rate); cross infection/prevention & control + hand disinfection + (healthcare-associated infections + rate); hand hygiene + healthcare-associated

infection rate + prevention; and alcohol-based hand rub + healthcare-associated infections. Google Scholar was searched using the following combination of terms: hand hygiene + healthcare-associated infections + rate. Titles of publications in English were reviewed. Abstracts of articles of potential interest were reviewed, and those determined to be of sufficient interest were downloaded and the text of articles were reviewed. Only studies that reported on HAI rates and information regarding hand hygiene compliance were noted. Bibliographies of downloaded articles were also reviewed for pertinent studies. Authors of 45 publications of interest which did not provide data on the ABHR format used were sent emails requesting information regarding the ABHR format utilized during the respective study periods.

Data recorded for each study included the publication year, first author, ABHR format used, study time period(s), the country or countries in which the study occurred, the impact on hand hygiene compliance rates and on various healthcare outcomes. The impact on MDRO colonization/acquisition rates was included as a healthcare outcome, because such rates are directly affected by the effects that hand hygiene has on transmission of pathogens. Differences in proportions were analyzed using Chi-square tests, while continuous data were compared using the Kruskal–Wallis test.

Results

Factors affecting antimicrobial efficacy

Factors that have been shown to affect the ability of ABHRs to reduce bacterial counts on hands include the volume of ABHR applied to hands, the amount of time that hands must be rubbed together before they feel dry (so-called dry time), ABHR formulation, and methods used to conduct in-vivo efficacy studies [11, 12].

Volume of ABHR applied

Multiple studies have demonstrated that the greater the volume of ABHR applied to hands, the greater the log₁₀ reduction of viable bacteria on hands [13–19]. Increasing the volume of ABHR applied to hands also increases dry times [16–21].

Dry time

The antimicrobial efficacy of ABHRs is also affected by dry times [13, 16, 18, 20]. Importantly, dry time is a major driver of antimicrobial efficacy, independent of the volume applied [18]. To achieve acceptable antimicrobial efficacy, the WHO Guideline for Hand Hygiene in Health Care recommends that dry times should be a minimum of 20 s when performing hand hygiene with an ABHR [22], while the 2022 SHEA/IDSA/APIC Practice Recommendation on hand hygiene recommends that dry times

should be a minimum of 15 s [10]. Since some health-care personnel rub their hands together for less than 5 to 10 s [23–25], hand hygiene education programs should emphasize the importance of achieving recommended dry times.

ABHR formulation

Several studies have found that ABHR formulation can influence antimicrobial efficacy [8, 16, 26]. For example, Edmonds et al. [8] found that a novel 70% ethanol gel yielded significantly higher log₁₀ reductions after one and after 10 applications than two other 70% ethanol gel formulations, and that a novel 70% ethanol foam yielded significantly higher log₁₀ reductions after one and 10 applications than another 70% ethanol foam formulation. Barbut et al. [26] found that a rinse formulation containing 30% n-propanol, 45% isopropanol and 0.2% mecetronium ethyl-sulphate (total alcohol content 75%) and a gel formulation containing a higher alcohol content (85% ethanol) yielded nearly identical log₁₀ reductions, despite the higher total alcohol content of the latter. Macinga et al. [27] found that gel formulations ranging from 62%, 70% and 85% ethanol yielded log₁₀ reductions that were not significantly different. Another study revealed that a 70% ethanol foam yielded a mean log₁₀ reduction that was not statistically different from those achieved by an 80% ethanol rinse, and a 90% gel, demonstrating that formulation constituents other than alcohol can affect efficacy [16]. Overall, the above studies demonstrate that formulation is more important than alcohol concentration alone in determining antimicrobial efficacy.

ABHR formulation can also affect dry times [16, 28, 29]. Dry times vary when different ABHR products are applied with the same volume [28]. ABHRs with higher ethanol concentrations dry faster, regardless of the format [16].

Does ABHR format (rinse, gel, foam) affect efficacy?

A 2002 study using the EN 1500 method compared the log₁₀ reductions achieved by 10 “first generation” gels with alcohol concentrations from 53 to 70% and by four rinses containing from 64 to 75% alcohol to the reference alcohol (60% 2-propanol). None of the gels met EN 1500 criteria for efficacy, while all four rinses did [1]. Based on the study results, efforts were made to improve the antimicrobial efficacy of gels. Of note, foams were rarely used when the study was performed.

Several more recent studies have shown that ABHR format (rinse, gel, foam) does not have a major impact on in vivo antimicrobial efficacy [8, 16, 29, 30]. One study that evaluated the effect of different ASTM test methods on antimicrobial efficacy of a gel and a foam (both 70% ethanol) found that the test method used significantly affected antimicrobial efficacy, but ABHR format did not [30]. Table 1 shows the results for three studies that assessed the influence of product format on antimicrobial efficacy by using the EN 1500 method [8, 16, 29].

Accordingly, if ABHR format makes a difference in the abilities of ABHR rinses, gels, and foams to reduce HAIs, it is unlikely to be due to differences in antimicrobial efficacy. Several studies suggest that ABHR format is not a major determinant of dry time [16, 26, 31]. The above study by Wilkinson et al. [29] found rinses or foams were

Table 1 Log₁₀ reductions achieved by liquid, gel and foam ABHRs in three studies using EN 1500 methods

Author	Format	Application Volume (ml)	Mean log ₁₀ Reduction at 3 ml	Mean log ₁₀ Reduction at 3 ml × 2	P value
Edmonds [8]	Gel – 70% ETOH	3	5.25	5.11	N.S.D
	Gel – 70% ETOH	3	5.17	4.8	N.S.D
	Foam – 70% ETOH	3	5.06	5.11	N.S.D
Macinga [16]	Rinse – 60% IPA	3 ml × 2		4.63	
	Rinse – 80% ETOH	3	4.50		0.68*
	Gel – 90% ETOH	3	4.61		0.99*
	Foam – 70% ETOH	3	4.56		0.93*
Wilkinson [29]	Rinse – 60% IPA	3	4.19		N.S.D
	Gel – 60% IPA	3	4.26		N.S.D
	Foam – 60% IPA	3	4.22		N.S.D
	Rinse – 80% ETOH	3	4.03		N.S.D
	Gel – 80% ETOH	3	4.52		N.S.D
	Foam – 80% ETOH	3	4.34		N.S.D

ETOH Ethanol, IPA Isopropanol, N.S.D. Not statistically different

* P value compared to EN 1500 reference solution

perceived by HCP to dry more quickly than gels, but format did not result in significant differences in antimicrobial efficacy.

Methods for in-vivo efficacy studies

The in-vivo methods used to study ABHRs can also affect conclusions regarding their efficacy [8, 18, 27, 30]. For example, using a smaller volume of fluid to artificially contaminate hands can yield greater \log_{10} reductions [27]. \log_{10} reductions achieved with the ASTM E1174 method can differ substantially compared with those obtained with the EN 1500 standard [8]. And ASTM methods E1174, E2755 and E2784 yield different estimates of efficacy [30]. In addition, a modified EN 1500 protocol based on rubbing hands until dry found that \log_{10} reductions were greater when larger volumes of ABHR were applied [18].

Factors that likely impact ABHR effectiveness

In addition to antimicrobial efficacy, a number of other factors are likely to influence the ability of ABHRs to reduce HAIs (i.e., their effectiveness) [11, 12].

Level of acceptance by healthcare personnel

Poor skin tolerance (dryness or irritation), an unpleasant feeling of ABHR during or after application, an unfavorable smell and prolonged drying time, all of which can be affected by ABHR formulation, can affect healthcare personnel (HCP) preferences and may reduce acceptance by HCP [26, 32–38]. HCP prefer products that are least likely to result in skin dryness compared to those that are prone to cause dryness with repeated use [32, 39]. Some HCP prefer ethanol-based ABHRs to isopropanol-containing agents based on differences in their smell [26, 37]. HCP prefer ABHRs that are easier to contain in the hand and less likely to drip [36, 37]. HCP are less likely to use a product with a lower acceptance rate [26]. Higher levels of acceptance of an ABHR can lead to greater hand hygiene compliance [34].

Volume of ABHR delivered

The volume of ABHR applied, an important factor in achieving the desired antimicrobial efficacy, can vary substantially based on the amount HCP choose to use and by the volume delivered by dispensers [9, 40–45]. Application of suboptimal volumes of ABHR by HCP will decrease the antimicrobial efficacy of hand hygiene [15, 18], and may adversely affect the impact of hand hygiene on prevention of HAIs.

Hand hygiene compliance rates by HCP

Multiple studies have found that the rate of hand hygiene compliance by HCP can influence transmission of

healthcare-associated pathogens and HAIs, with reductions in transmission and HAIs occurring with higher compliance rates [46–48].

A combination of the above factors likely impacts the ability of ABHRs, independent of their antimicrobial efficacy or format, to reduce HAIs. In addition, there is substantial evidence that most facilities that have improved hand hygiene compliance rates and reduced transmission of healthcare pathogens and/or HAIs have implemented multimodal hand hygiene improvement strategies such as the one recommended by the WHO Guidelines for Hand Hygiene in Health Care [22], and have often implemented other strategies not related to hand hygiene [49]. As a result, the availability of ABHR, accompanied by little or no additional complementary components, is not likely to improve hand hygiene compliance [50], and will probably have little impact on HAIs.

Results of the literature review

Database searches yielded a combined total of 1,948 titles, with review of 318 abstracts. The full texts of 114 articles were downloaded. Emails requesting data on ABHR format were sent to 45 authors, of whom 34 responded. Data from 67 publications are included in the review. The primary results of the literature review are presented in Table 2.

The ABHR formats used in the 67 studies were rinses ($n=27$), gels ($n=28$) and foams ($n=12$). The proportion of studies published >10 years ago was slightly, but not significantly, higher for rinses (44.4%) and gels (57.1%) than for foams (41.7%) ($p>0.05$).

The duration of the study periods ranged from 4 months to 11 years, with the following median study durations (in months): rinses=43.2; gels=28.2; foam=34.3 ($p>0.05$). The countries in which the studies were conducted differed significantly for the different formats. None of 27 studies using rinses were conducted in the United States or Canada, whereas 11/28 (39.3%) of gel studies and 12/12 (100%) of foam studies were conducted in North America ($p<0.001$). Hand hygiene compliance rates were not reported in 14 studies, although 9 of these reported increased ABHR consumption. Of the remaining 53 studies, 51 reported improved hand hygiene compliance rates, one study utilizing a rinse reported no significant change, and one utilizing a gel reported a decrease in compliance.

Of the 67 studies, all but two gel studies, one of which found no improvement in hand hygiene compliance, reported some decrease in HAIs or MDRO colonization/acquisition rates (Table 2). However, not all studies that reported decreases reported a statistically significant decrease in healthcare outcomes. The proportion of studies in which a significant decrease in one or more healthcare

Table 2 Publication year, ABHR format, study time period, country in which the study was performed, impact on hand hygiene compliance and healthcare outcome

Pub Date	First Author	ABHR Format	Time period	Country	Healthcare Outcome
2000	Pittet [46]	liquid	1993–1998	Switzerland	Significant decrease in HAIs and MRSA transmission
2004	Won [51]	liquid	1997–2001	Taiwan	Significant decrease in HAIs
2007	Pessoa-Silva [52]	liquid	Mar 2001-Feb 2004	Switzerland	Decrease in BSIs in NICU
2008	Nguyen [53]	liquid	Apr—Dec 2007	Vietnam	Significant decrease in HAIs
2009	Souweine [54]	liquid	Apr 2003-Jan 2004	France	Decrease in MRSA colonization/infection
2010	Cheng [55]	liquid	Jan 2002-Jun 2009	Hong Kong	Significant decrease in MRSA infections, including MRSA BSIs
2011	Chen [56]	liquid	Jan 1999-Dec 2007	Taiwan	Significant decrease in HAIs
2011	Barrera [57]	liquid	Feb-Jun 2002	Columbia	Significant decrease in CLABSIs, not other HAIs
2012	Monistrol [58]	liquid	Feb 2007-Jan 2008	Spain	Decrease in MRSA acquisition; no change in HAIs
2012	Ho [59] ^a	liquid	Nov 2009-Jul 2010	Hong Kong	Significant decrease in respiratory and MRSA infections
2012	Ling [60]	liquid	Jan 2007-Dec 2010	Singapore	Decrease (borderline) in HA-MRSA infections
2012	Lee [61]	liquid	Jan 2004-Dec 2010	Taiwan	Significant decrease in HA-MRSA infections
2015	Thi Anh Thu [62]	liquid	Jun 2009-Apr 2011	Vietnam	Significant decrease in HAIs
2015	Sadeghi-Moghaddam [63]	liquid	Apr 2010-Mar 2014	Iran	Significant decrease in HAIs
2016	Cheng [64]	liquid	Jul 2011-Oct 2015	Hong Kong	Significant decrease in VRE transmission
2017	Saito [65]	liquid	Oct 2014-Apr 2015	Uganda	Significant decrease in HAIs/SIRs in pediatric & surgical dept
2018	Allegranzi [66]	liquid	Jul 2013-Dec 2015	African countries	Significant decrease in surgical site infections
2018	Grayson [67]	liquid	2009–2017	Australia	Significant decrease in healthcare-associated <i>S. aureus</i> bacteremia
2019	von Lengerke [68] ^a	liquid	2013–2015	Germany	Significant decrease in MDROs
2019	Hagel [69]	liquid	Sep 2011-Aug 2012 May 2013-Aug 2014	Germany	No change in overall HAIs; Significant decrease in severe ICU HAIs
2020	Aghdassi [70] ^a	liquid	Dec 2017-Dec 2018	Germany	Significant decrease in device-related BSIs
2020	Phan [71]	liquid	2010–2018	Vietnam	Significant decrease in HAIs
2021	Knudsen [72]	liquid	Feb 2020-Jan 2021	Denmark	Significant decrease in HAIs
2021	Lo [73]	liquid	2018-May 2020	Taiwan	Significant decrease in CRAB and VRE infections

Table 2 (continued)

Pub Date	First Author	ABHR Format	Time period	Country	Healthcare Outcome
2022	Fukushige [74]	liquid	2018–2020	Taiwan	Significant decrease in overall HAIs; not in MRSA or VRE HAIs
2022	Gonzalez-Gonzalez [75]	liquid	2009–2019	Mexico	Significant decrease in CLABSIs
2023	Rosenfeldt Knudsen [76]	liquid	Feb 2020-Jun 2022	Denmark	Significant decrease in HABSIs; no significant change in CAUTIs
2002	Fendler [77]	gel	Jul 1997-May 2000	USA	Significant decrease in HAIs
2003	Hilburn [78]	gel	Feb 2000-May 2001	USA	Significant decrease in HAIs
2004	MacDonald [79]	gel	Mar 2000-Nov 2000	Scotland	Significant decrease in MRSA acquisition
2007	Murthy [80]	gel	1999–2003	USA	Significant decrease in nosocomial MRSA BSIs
2007	Harrington [81]	gel	Jan 2003-May 2007	Australia	Significant decrease in MRSA BSI
2008	Rupp [3]	gel	Aug 2001-Sep 2003	USA	No change in device-related infections/MDROs/CDI
2009	Al-Naami [82]	gel	Oct 2007-Juh 2008	Saudi Arabia	Decrease in surgical site infections
2010	Carboneau [83]	gel	Mar 2006-Feb 2007	USA	Non-significant decrease in nosocomial MRSA infections
2011	Yeung [84] ^a	gel	Jan 2007 -Oct 2007	Hong Kong	Significant decrease in HAIs
2011	Marra [85]	gel	Jul 2008-Dec 2009	Brazil	Significant decrease in device-related HAIs
2011	Garcia-Vazquez [86]	gel	Not stated	Spain	Significant decrease in HAIs
2012	Kirkland [87]	gel	Jan 2006-Nov 2009	USA	Significant decrease in HAIs
2012	Mestre [88]	gel	Mar 2007-Dec 2011	Spain	Significant decrease in healthcare-acquired MRSA
2013	Talbot [89]	gel	Jan 2007-Aug 2012	USA	Significant decrease in device-related infections
2013	Salama [90]	gel	Feb 2011 – Aug 2011	Kuwait	Significant decrease in HAIs
2013	Iacobelli [91]	gel	Jan 2007-Dec 2009	France	Significant decrease in MRSA infections and colonization
2014	Johnson [92]	gel	Apr 2006—Sep 2012	USA	Significant decrease in CLABSIs
2015	Fox [93]	gel	Dec 2009-Feb 2012	USA	Decrease in CLABSIs and CAUTIs
2015	Chun [94]	gel	Oct 2008-Jan 2009	South Korea	Significant decrease in MRSA acquisition and colonization pressure
2016	Shabot [95]	gel	Oct 2010-Dec 2014	USA	Significant decrease in ICU CLABSI and VAP
2018	Ragusa [96]	gel	2015–2016	Italy	Increase in CDI
2018	Al-Tawfiq [97]	gel	2014-Sep 2015	Saudi Arabia	Decreases in CDI, CLABSIs and CAUTIs

Table 2 (continued)

Pub Date	First Author	ABHR Format	Time period	Country	Healthcare Outcome
2018	De la Rosa-Zamboni [98]	gel	Jan 2013—Aug 2013	Mexico	Significant decrease in HAIs
2018	Lenz [99]	gel	Jun 2011-Apr 2012	Argentina	Significant decrease in CABSIs
2020	Ojanpera [100]	gel	2013–2018	Finland	Significant decrease in HAIs
2021	Banks [101]	gel	Jun 2017-Jul 2019	USA	Significant decrease in CDI
2021	Akkoc [102]	gel	Apr 2016—Aug 2016	Turkey	Significant decrease in HAIs, with non-significant decrease in device-related infections
2023	Ragonese [103]	gel	Nov 2017-Dec 2020	Italy	Significant decrease in HA-CRE colonization rate
2004	Swoboda [104]	foam	Jul 2000-Oct 2001	USA	Significant decrease in MRSA or VRE infection/colonization; non-significant decrease in overall HAIs
2010	Helms [105]	foam + gel	Aug 2007-Jun 2008	USA	Non-significant decrease in HAIs
2010	Knight [106]	foam	Jan 2001-Jun 2008	USA	Significant decrease in HO-CDI
2013	Raschka [107]	gel—> foam	2007–2011	Canada	Non-significant decrease in selected HAIs
2013	Schweon [108]	foam	May 2009-Feb 2011	USA	Significant decrease in lower respiratory infections; Decrease in skin & soft tissue infections
2016	Sickbert-Bennett [109]	foam	Oct 2013-Feb 2015	USA	Significant decrease in HAIs
2016	Kelly [110]	foam	Jul 2012-Mar 2015	USA	Significant decrease in MRSA infections
2018	McCalla [111]	foam	Jan 2014-Sep 2017	USA	Significant decrease in CLABSIs and CAUTIs
2019	Boyce [112]	foam	Jun 2014-Jun 2018	USA	Decrease in non-CDI; increase in CDI
2020	Leis [113] ^a	foam	Jun 2017-Dec 2018	Canada	Non-significant decrease in MRSA colonization/infection; not HA-BSIs or CDI
2020	Knepper [114]	foam	July 2016-Dec 2017	USA	Significant decrease in CDI. No change in other HAIs
2023	Barrett [115]	foam	Feb 2018-Sep 2021	USA	Significant decrease in MRSA infections

^a Healthcare Outcome refers to reduced transmission of healthcare pathogens and/or healthcare-associated infections. *HAIs* Healthcare-associated infections, *MRSA* Methicillin-resistant *S. aureus*, *BSIs* Bloodstream infections, *NICU* Neonatal intensive care unit, *CLABSIs* Central line-associated bloodstream infections, *HA-MRSA* Healthcare-associated MRSA, *VRE* Vancomycin-resistant enterococci, *SIRs* Standardized infection ratios, *MDROs* Multidrug-resistant organisms, *ICU* Intensive care unit, *CRAB* Carbapenem-resistant *Acinetobacter baumannii*, *HABSIs* Healthcare-associated BSIs, *CAUTIs* Catheter-associated urinary tract infections, *CDI* *Clostridioides difficile* infection, *VAP* Ventilator-associated pneumonia, *CABSIs* Catheter-associated BSIs, *HA-CRE* Healthcare-associated carbapenem-resistant *Enterobacteriaceae*, *HO-CDI* Hospital-onset CDI

outcomes occurred was as follows: rinses (23/27, 85.2%); gels (22/28, 78.6%); and foams (8/12; 75%) ($p > 0.05$).

Discussion

In the intervening years since the WHO Guidelines for Hand Hygiene for Health Care was published in 2009, a debate has emerged regarding the relative antimicrobial efficacy of the different formats of ABHRs and their ability to contribute to reduction of HAIs. Recent evidence suggests that ABHR dry time is the primary driver of antimicrobial efficacy, independent of the volume applied [18]. Furthermore, additional studies provide evidence that ABHR rinses, gels, and foams have comparable in-vivo antimicrobial efficacy [8, 16, 29, 30]. Accordingly, it may be reasonable to assume that any potential differences in the ability of the different ABHR formats to contribute to the reduction of healthcare-associated pathogen transmission and HAIs are unlikely to be related to their antimicrobial efficacy, provided that those ABHRs meet the ASM or EN norms. Other factors more likely to affect the ability of different ABHRs to contribute to HAI reduction include the volume of handrub applied to the hands, dry times, product formulation, acceptance by HCP, and resulting hand hygiene compliance rates. HCP prefer ABHRs that dry quickly, so that hand hygiene action takes less time. But currently available data are somewhat contradictory regarding which format routinely provides the shortest dry times. For example, one study found similar dry times for the 3 formats [16], while others have reported that dry times appeared to be shorter for rinses [38], or that rinses and foams dry more quickly than gels [29].

The striking differences in the geographical locations in which the studies of the different formats were conducted (no rinse studies and all foam studies conducted in North America) is an interesting finding, the explanation for which was not provided by the review. Factors that may help explain this phenomenon include efficacy results obtained with different testing protocols (EN1500 in Europe vs ASTM methods often used in the United States), cultural considerations, influence of local and regional hand hygiene experts, and marketing strategies of ABHR manufacturers. The review suggests that the antimicrobial efficacy of the three formats is unlikely to explain this phenomenon.

The literature review has several limitations. Not all published studies reporting the impact of hand hygiene on HAI rates were included due to the lack of available data regarding the ABHR format used. Compared to rinses and gels, there were substantially fewer studies that involved the use of ABHR foams, which may have affected the results. There is considerable heterogeneity in the study designs utilized and in the completeness of data provided. Of the 67 studies, only 4 were cluster randomized controlled trials [59, 68, 70, 113], and one

was a prospective, controlled trial with cross-over design [3]. Most of the studies were before-after quasi-experimental observational studies. No statistical analysis was provided in several studies (rinse – 1, gel – 1, foam – 2) [60, 83, 105, 107], precluding the ability to determine if decreases in HAIs were statistically significant. A majority of the studies did not report the alcohol concentration of the ABHRs used. However, 28 studies (performed between 1993 and 2022) that reported product details used ABHRs with alcohol concentrations ranging from 60 to 95% (most were 62% to 75%), which is within the range that the WHO hand hygiene guideline regards as the most effective [22]. In addition to providing ABHRs available to HCP, virtually all studies implemented additional complementary strategies such as those recommended by the WHO [22, 116], making it impossible to attribute decreases in healthcare outcomes solely to the availability, antimicrobial efficacy, or format of ABHR.

Due to its multiple shortcomings, the literature review failed to identify a format that was significantly better in yielding statistically significant reductions in the healthcare outcomes measured. The limitations of the literature review make it clear that much more rigorous methods are needed to identify which format reduces HAI most effectively, if in fact any differences exist.

To definitively answer if any format is significantly more effective, a prospective multicenter, cluster randomized controlled trial of 6 to 12 months duration would most likely be needed to determine if ABHR format, by itself, is an independent predictor of effectiveness. Importantly, in healthcare institutions where HAI rates are extremely low, the study duration might be even longer, ie. up to 36 months. If it were feasible, including a cross-over feature and performance in different countries would be desirable. Such a trial would need to address multiple potential confounding factors. Ideally, study sites would need to have comparable patient populations, hand hygiene compliance rates obtained with similar methods, HAI definitions and surveillance methods. And the ABHR rinses, gels and foams tested should have comparable in-vivo antimicrobial efficacy, dispensing systems delivering the same volumes of product, and HCP acceptance rates. The likelihood that such a trial will be conducted appears to be slim at best.

As pointed out recently, there are several other issues related to ABHRs that warrant further research that should be feasible [117]. There is a need for additional high-quality evidence-based trials to compare the in-vivo antimicrobial activity of rinses, gels, foams and sprays, and new clinical studies to assess the skin tolerance and HCP acceptance of ABHRs, their frequency of use, and the impact of these factors on hand hygiene compliance rates [117]. Because there is increasing evidence that

ABHR dispensers which deliver the same dose to HCP may result in suboptimal dry times in HCP with relatively large hands, continued efforts to develop dispensers capable of dispensing volumes based on an individual healthcare worker's hand size are needed [18, 117].

Conclusions

ABHR format is not a major driver of antimicrobial efficacy, provided the product meets recommended standards [22, 118, 119]. In light of studies suggesting that properly formulated rinse, gel, and foam ABHRs have similar antimicrobial efficacy, it is perhaps not surprising that all formats have been associated with successful efforts to improve hand hygiene compliance, when incorporated into a multimodal improvement strategy. Current evidence is insufficient to definitively determine if one ABHR format is more effective in reducing transmission of healthcare-associated pathogens and HAIs.

Authors' contributions

The concept of reviewing of the topic was conceived by D.P. J.B. performed all literature searches, downloaded and reviewed pertinent articles and prepared the initial manuscripts. DP critically reviewed the advanced manuscripts and made important revisions.

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Availability of data and materials

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

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Competing interests

JMB is a consultant, has received travel support from and presented at scientific meetings sponsored by GOJO Industries. JMB is also a consultant to Diversey.

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References

- Kramer A, Rudolph P, Kampf G, Pittet D. Limited efficacy of alcohol-based hand gels. *Lancet*. 2002;359(9316):1489–90.
- Dharan S, Hugonnet S, Sax H, Pittet D. Comparison of waterless hand antiseptics agents at short application times: raising the flag of concern. *Infect Control Hosp Epidemiol*. 2003;24(3):160–4.
- Rupp ME, Fitzgerald T, Puumala S, Anderson JR, Craig R, Iwen PC, et al. Prospective, controlled, cross-over trial of alcohol-based hand gel in critical care units. *Infect Control Hosp Epidemiol*. 2008;29(1):8–15.
- Kampf G, Marschall S, Eggerstedt S, Ostermeyer C. Efficacy of ethanol-based hand foams using clinically relevant amounts: a cross-over controlled study among healthy volunteers. *BMC Infect Dis*. 2010;10:78.
- Widmer AF, Rotter M. Effectiveness of alcohol-based hand hygiene gels in reducing nosocomial infection rates. *Infect Control Hosp Epidemiol*. 2008;29(6):576; author reply 80–2.
- Mermel LA, Boyce JM, Voss A, Allegranzi B, Pittet D. Trial of alcohol-based hand gel in critical care units. *Infect Control Hosp Epidemiol*. 2008;29(6):577–9; author reply 80–2.
- Kampf G, Ruselack S, Eggerstedt S, Nowak N, Bashir M. Less and less-influence of volume on hand coverage and bactericidal efficacy in hand disinfection. *BMC Infect Dis*. 2013;13:472.
- Edmonds SL, Macinga DR, Mays-Suko P, Duley C, Rutter J, Jarvis WR, et al. Comparative efficacy of commercially available alcohol-based hand rubs and World Health Organization-recommended hand rubs: formulation matters. *Am J Infect Control*. 2012;40(6):521–5.
- Macinga DR, Edmonds SL, Campbell E, Shumaker DJ, Arbogast JW. Efficacy of novel alcohol-based hand rub products at typical in-use volumes. *Infect Control Hosp Epidemiol*. 2013;34(3):299–301.
- Glowicz JB, Landon E, Sickbert-Bennett EE, Aiello AE, 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(3):355–76.
- Huang GK, Stewardson AJ, Grayson ML. Back to basics: hand hygiene and isolation. *Curr Opin Infect Dis*. 2014;27(4):379–89.
- Price L, Gozdzielewska L, Alejandre JC, Jorgenson A, Stewart E, Pittet D, et al. Systematic review on factors influencing the effectiveness of alcohol-based hand rubbing in healthcare. *Antimicrob Resist Infect Control*. 2022;11(1):16.
- Kampf G. How effective are hand antiseptics for the postcontamination treatment of hands when used as recommended? *Am J Infect Control*. 2008;36(5):356–60.
- Gorony-Bermes P, Koburger T, Meyer B. Impact of the amount of hand rub applied in hygienic hand disinfection on the reduction of microbial counts on hands. *J Hosp Infect*. 2010;74(3):212–8.
- Bellissimo-Rodrigues F, Soule H, Gayet-Ageron A, Martin Y, Pittet D. Should alcohol-based handrub use be customized to healthcare workers' hand size? *Infect Control Hosp Epidemiol*. 2016;37(2):219–21.
- Macinga DR, Shumaker DJ, Werner HP, Edmonds SL, Leslie RA, Parker AE, et al. The relative influences of product volume, delivery format and alcohol concentration on dry-time and efficacy of alcohol-based hand rubs. *BMC Infect Dis*. 2014;14:511.
- Li X, Xu CJ, Zhao SJ. Experimental study on disinfection effect of different dose of rapid hand disinfectant. *Int J Nurs Sci*. 2014;1:212–4.
- Suchomel M, Leslie RA, Parker AE, Macinga DR. How long is enough? Identification of product dry-time as a primary driver of alcohol-based hand rub efficacy. *Antimicrob Resist Infect Control*. 2018;7:65.
- Wilkinson MAC, Ormandy K, Bradley CR, Fraise AP, Hines J. Dose considerations for alcohol-based hand rubs. *J Hosp Infect*. 2017;95(2):175–82.
- Kenters N, Eikelenboom-Boskamp A, Hines J, McGeer A, Huijskens EGW, Voss A. Product dose considerations for real-world hand sanitizer efficacy. *Am J Infect Control*. 2020;48(5):503–6.
- Voniatis C, Bansaghi S, Ferencz A, Haidegger T. A large-scale investigation of alcohol-based handrub (ABHR) volume: hand coverage correlations utilizing an innovative quantitative evaluation system. *Antimicrob Resist Infect Control*. 2021;10(1):49.
- World Health O. WHO guidelines for hand hygiene in health care. Geneva: World Health Organization; 2009. http://whqlibdoc.who.int/publications/20099789241597906_eng.pdf.
- Clack L, Scotoni M, Wolfensberger A, Sax H. "First-person view" of pathogen transmission and hand hygiene - use of a new head-mounted video capture and coding tool. *Antimicrob Resist Infect Control*. 2017;6:108.
- Helder OK, Brug J, Looman CW, van Goudoever JB, Kornelisse RF. The impact of an education program on hand hygiene compliance and nosocomial infection incidence in an urban neonatal intensive care unit: an intervention study with before and after comparison. *Int J Nurs Stud*. 2010;47(10):1245–52.

25. Stahmeyer JT, Lutze B, von Lengerke T, Chaberny IF, Krauth C. Hand hygiene in intensive care units: a matter of time? *J Hosp Infect.* 2017;95(4):338–43.
26. Barbut F, Maury E, Goldwirt L, Boelle PY, Neyme D, Aman R, et al. Comparison of the antibacterial efficacy and acceptability of an alcohol-based hand rinse with two alcohol-based hand gels during routine patient care. *J Hosp Infect.* 2007;66(2):167–73.
27. Macinga DR, Beausoleil CM, Campbell E, Mulberry G, Brady A, Edmonds SL, et al. Quest for a realistic in vivo test method for antimicrobial hand-rub agents: introduction of a low-volume hand contamination procedure. *Appl Environ Microbiol.* 2011;77(24):8588–94.
28. Girard R, Aupepe M, Erb M, Bettinger A, Jouve A. Hand rub dose needed for a single disinfection varies according to product: a bias in benchmarking using indirect hand hygiene indicator. *J Epidemiol Glob Health.* 2012;2(4):193–8.
29. Wilkinson MAC, Ormandy K, Bradley CR, Hines J. Comparison of the efficacy and drying times of liquid, gel and foam formats of alcohol-based hand rubs. *J Hosp Infect.* 2018;98(4):359–64.
30. Edmonds-Wilson S, Campbell E, Fox K, Macinga D. Comparison of 3 in vivo methods for assessment of alcohol-based hand rubs. *Am J Infect Control.* 2015;43(5):506–9.
31. Voniatis C, Bansaghi S, Veres DS, Szeremy P, Jedlovsky-Hajdu A, Szijarto A, et al. Evidence-based hand hygiene: Liquid or gel handrub, does it matter? *Antimicrob Resist Infect Control.* 2023;12(1):12.
32. Kramer A, Bernig T, Kampf G. Clinical double-blind trial on the dermal tolerance and user acceptability of six alcohol-based hand disinfectants for hygienic hand disinfection. *J Hosp Infect.* 2002;51(2):114–20.
33. Pittet D, Allegranzi B, Sax H, Chraïti MN, Griffiths W, Richet H. Double-blind, randomized, crossover trial of 3 hand rub formulations: fast-track evaluation of tolerability and acceptability. *Infect Control Hosp Epidemiol.* 2007;28(12):1344–51.
34. Traore O, Hugonnet S, Lubbe J, Griffiths W, Pittet D. Liquid versus gel handrub formulation: a prospective intervention study. *Crit Care.* 2007;11(3):R52.
35. Wolfensberger A, Durisch N, Mertin J, Ajdler-Schaeffler E, Sax H. Evaluating the tolerability and acceptability of an alcohol-based hand rub - real-life experience with the WHO protocol. *Antimicrob Resist Infect Control.* 2015;4:18.
36. Greenaway RE, Ormandy K, Fellows C, Hollowood T. Impact of hand sanitizer format (gel/foam/liquid) and dose amount on its sensory properties and acceptability for improving hand hygiene compliance. *J Hosp Infect.* 2018;100(2):195–201.
37. Peters A, Cave C, Carry J, Sauser J, Pittet D. Tolerability and acceptability of three alcohol-based hand-rub gel formulations: a randomized crossover study. *J Hosp Infect.* 2022;123:112–8.
38. Verwilghen D, Osiak K, Shaw AD, Averay K, Kampf G, van Galen G. Identifying drivers for user preference and acceptability of different hydro-alcoholic hand rub formulations. *J Hosp Infect.* 2021;117:17–22.
39. Girard R, Bousquet E, Carre E, Bert C, Coyault C, Coudrais S, et al. Tolerance and acceptability of 14 surgical and hygienic alcohol-based hand rubs. *J Hosp Infect.* 2006;63(3):281–8.
40. Helder OK, van Goudoever JB, Hop WC, Brug J, Kornelisse RF. Hand disinfection in a neonatal intensive care unit: continuous electronic monitoring over a one-year period. *BMC Infect Dis.* 2012;12:248.
41. Scheithauer S, Bickenbach J, Heisel H, Fehling P, Marx G, Lemmen S. Do WiFi-based hand hygiene dispenser systems increase hand hygiene compliance? *Am J Infect Control.* 2018;46(10):1192–4.
42. Leslie RA, Donskey CJ, Zabarsky TF, Parker AE, Macinga DR, Assadian O. Measuring alcohol-based hand rub volume used by healthcare workers in practice. *Antimicrob Resist Infect Control.* 2015;7:P295.
43. Martinello RA, Arbogast JW, Guercia K, Parker AE, Boyce JM. Nursing preference for alcohol-based hand rub volume. *Infect Control Hosp Epidemiol.* 2019;40(11):1248–52.
44. Pires D, Gayet-Ageron A, Guitart C, Robert YA, 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(2):e2035331.
45. Bansaghi SAS, Szeremy P, Smioth NM, McNulty JJ, Arbogast JW, Haidegger T. Comparison of dispensers dosing consistency using different format (foam and gel) handrub. Geneva: International Conference on Prevention & Infection Control; 2023.
46. Pittet D, Hugonnet S, Harbarth S, Mourouga P, Sauvan V, Touveneau S. Effectiveness of a hospital-wide programme to improve compliance with hand hygiene. *Lancet.* 2000;356:1307–12.
47. Allegranzi B, Harbarth S, Pittet D. Effect of hand hygiene on infection rates. In: Pittet D, Boyce JM, Allegranzi B, editors. *Hand hygiene: a handbook for medical professionals.* Hoboken: Wiley-Blackwell; 2017. p. 299–316.
48. Mouajou V, Adams K, DeLisle G, Quach C. Hand hygiene compliance in the prevention of hospital-acquired infections: a systematic review. *J Hosp Infect.* 2022;119:33–48.
49. McLaws ML. The relationship between hand hygiene and health care-associated infection: it's complicated. *Infect Drug Resist.* 2015;8:7–18.
50. Muto CA, Siström MG, Farr BM. Hand hygiene rates unaffected by installation of dispensers of a rapidly acting hand antiseptic. *Am J Infect Control.* 2000;28:273–6.
51. Won SP, Chou HC, Hsieh WS, Chen CY, Huang SM, Tsou KI, et al. Handwashing program for the prevention of nosocomial infections in a neonatal intensive care unit. *Infect Control Hosp Epidemiol.* 2004;25(9):742–6.
52. Pessoa-Silva CL, Hugonnet S, Pfister R, Touveneau S, Dharan S, Posfay-Barbe K, et al. Reduction of health care associated infection risk in neonates by successful hand hygiene promotion. *Pediatrics.* 2007;120(2):e382–90.
53. Nguyen KV, Nguyen PT, Jones SL. Effectiveness of an alcohol-based hand hygiene programme in reducing nosocomial infections in the Urology Ward of Binh Dan Hospital. *Vietnam Trop Med Int Health.* 2008;13(10):1297–302.
54. Souweine B, Lautrette A, Aumeran C, Bénédict M, Constantin JM, Bonnard M, et al. Comparison of acceptability, skin tolerance, and compliance between handwashing and alcohol-based handrub in ICUs: results of a multicentric study. *Intensive Care Med.* 2009;35(7):1216–24.
55. Cheng VC, Tai JW, Chan WM, Lau EH, Chan JF, To KK, et al. Sequential introduction of single room isolation and hand hygiene campaign in the control of methicillin-resistant *Staphylococcus aureus* in intensive care unit. *BMC Infect Dis.* 2010;10:263.
56. Chen YC, Sheng WH, Wang JT, Chang SC, Lin HC, Tien KL, et al. Effectiveness and limitations of hand hygiene promotion on decreasing healthcare-associated infections. *PLoS ONE.* 2011;6:e27163.
57. Barrera L, Zingg W, Mendez F, Pittet D. Effectiveness of a hand hygiene promotion strategy using alcohol-based handrub in 6 intensive care units in Colombia. *Am J Infect Control.* 2011;39(8):633–9.
58. Monistrol O, Calbo E, Riera M, Nicolas C, Font R, Freixas N, et al. Impact of a hand hygiene educational programme on hospital-acquired infections in medical wards. *Clin Microbiol Infect.* 2012;18(12):1212–8.
59. Ho ML, Seto WH, Wong LC, Wong TY. Effectiveness of multifaceted hand hygiene interventions in long-term care facilities in Hong Kong: a cluster-randomized controlled trial. *Infect Control Hosp Epidemiol.* 2012;33(8):761–7.
60. Ling ML, How KB. Impact of a hospital-wide hand hygiene promotion strategy on healthcare-associated infections. *Antimicrob Resist Infect Control.* 2012;1(1):13.
61. Lee YT, Chen SC, Lee MC, Hung HC, Huang HJ, Lin HC, et al. Time-series analysis of the relationship of antimicrobial use and hand hygiene promotion with the incidence of healthcare-associated infections. *J Antibiot (Tokyo).* 2012;65(6):311–6.
62. Thi Anh Thu L, Thi Hong Thoa V, Thi Van Trang D, Phuc Tien N, Thuy Van D, Thi Kim Anh L, et al. Cost-effectiveness of a hand hygiene program on health care-associated infections in intensive care patients at a tertiary care hospital in Vietnam. *Am J Infect Control.* 2015;43(12):93–9.
63. Sadeghi-Moghaddam P, Arjmandnia M, Shokrollahi M, Aghaali M. Does training improve compliance with hand hygiene and decrease infections in the neonatal intensive care unit? A prospective study. *J Neonatal Perinatal Med.* 2015;8(3):221–5.
64. Cheng VC, Tai JW, Chau PH, Lai CK, Chuang VW, So SY, et al. Successful control of emerging vancomycin-resistant enterococci by territory-wide implementation of directly observed hand hygiene in patients in Hong Kong. *Am J Infect Control.* 2016;44(10):1168–71.
65. Saito H, Inoue K, Ditai J, Wanume B, Abeso J, Balyejussa J, et al. Alcohol-based hand rub and incidence of healthcare associated infections in a rural regional referral and teaching hospital in Uganda (“WardGel” study). *Antimicrob Resist Infect Control.* 2017;6:129.

66. Allegranzi B, Aiken AM, Zeynep Kubilay N, Nthumba P, Barasa J, Okumu G, et al. A multimodal infection control and patient safety intervention to reduce surgical site infections in Africa: a multicentre, before-after, cohort study. *Lancet Infect Dis*. 2018;18(5):507–15.
67. Grayson ML, Stewardson AJ, Russo PL, Ryan KE, Olsen KL, Havers SM, et al. Effects of the Australian National Hand Hygiene Initiative after 8 years on infection control practices, health-care worker education, and clinical outcomes: a longitudinal study. *Lancet Infect Dis*. 2018;18(11):1269–77.
68. von Lengerke T, Ebadi E, Schock B, Krauth C, Lange K, Stahmeyer JT, et al. Impact of psychologically tailored hand hygiene interventions on nosocomial infections with multidrug-resistant organisms: results of the cluster-randomized controlled trial PSYGIENE. *Antimicrob Resist Infect Control*. 2019;8:56.
69. Hagel S, Ludewig K, Pletz MW, Frosinski J, Moeser A, Wolke M, et al. Effectiveness of a hospital-wide infection control programme on the incidence of healthcare-associated infections and associated severe sepsis and septic shock: a prospective interventional study. *Clin Microbiol Infect*. 2019;25(4):462–8.
70. Aghdassi SJS, Schroder C, Lemke E, Behnke M, Fliss PM, Plotzki C, et al. A multimodal intervention to improve hand hygiene compliance in peripheral wards of a tertiary care university centre: a cluster randomised controlled trial. *Antimicrob Resist Infect Control*. 2020;9(1):113.
71. Phan HT, Zingg W, Tran HTT, Dinh APP, Pittet D. Sustained effects of a multimodal campaign aiming at hand hygiene improvement on compliance and healthcare-associated infections in a large gynaecology/obstetrics tertiary-care centre in Vietnam. *Antimicrob Resist Infect Control*. 2020;9(1):51.
72. Knudsen AR, Kalle S, Hansen MB, Moller JK. Effectiveness of an electronic hand hygiene monitoring system in increasing compliance and reducing healthcare-associated infections. *J Hosp Infect*. 2021;115:71–4.
73. Lo SH, Lin CY, Hung CT, He JJ, Lu PL. The impact of universal face masking and enhanced hand hygiene for COVID-19 disease prevention on the incidence of hospital-acquired infections in a Taiwanese hospital. *Int J Infect Dis*. 2021;104:15–8.
74. Fukushige M, Syue LS, Morikawa K, Lin WL, Lee NY, Chen PL, et al. Trend in healthcare-associated infections due to vancomycin-resistant *Enterococcus* at a hospital in the era of COVID-19: More than hand hygiene is needed. *J Microbiol Immunol Infect*. 2022;55(6 Pt 2):1211–8.
75. Gonzalez-Gonzalez R, Huertas-Jimenez MA, Ochoa-Hein E, Galindo-Fraga A, Macias-Hernandez AE, De la Torre-Rosas A. Report of a multimodal strategy for improvement of hand hygiene compliance in a Latin American Hospital. How far from excellence? *J Patient Saf*. 2022;18(7):667–73.
76. Rosenfeldt Knudsen A, Bo Hansen M, Kjolseth MJ. Individual hand hygiene improvements and effects on healthcare-associated infections: a long-term follow-up study using an electronic hand hygiene monitoring system. *J Hosp Infect*. 2023;135:179–85.
77. Fendler EJ, Ali Y, Hammond BS, Lyons MK, Kelley MB, Vowell NA. The impact of alcohol hand sanitizer use on infection rates in an extended care facility. *Am J Infect Control*. 2002;30(4):226–33.
78. Hillburn J, Hammond BS, Fendler EJ, Groziak PA. Use of alcohol hand sanitizer as an infection control strategy in an acute care facility. *Am J Infect Control*. 2003;31(2):109–16.
79. MacDonald A, Dinah F, MacKenzie D, Wilson A. Performance feedback of hand hygiene, using alcohol gel as the skin decontaminant, reduces the number of inpatients newly affected by MRSA and antibiotic costs. *J Hosp Infect*. 2004;56(1):56–63.
80. Murthy RKDR, Harold JG, Silka P. Achieving sustained hand hygiene compliance by physicians. San Diego: Infectious Diseases Society of America 45th Annual Meeting, 2007.
81. Harrington G, Watson K, Bailey M, Land G, Borrell S, Houston L, et al. Reduction in hospitalwide incidence of infection or colonization with methicillin-resistant *Staphylococcus aureus* with use of antimicrobial hand-hygiene gel and statistical process control charts. *Infect Control Hosp Epidemiol*. 2007;28(7):837–44.
82. Al-Naami MYAM, Afzal MF, Al-Yami MS, Al-Qahtani SM, Al-Dohayan AD, El-Tinay OF, Karim AA, Khairy GA, Al-Saif AA, Zubaidi AM. Alcohol-based hand-rub versus traditional surgical scrub and the risk of surgical site infection: a randomized controlled equivalent trial. *EWMA J*. 2009;9:5–10.
83. Carboneau C, Benghe E, Jaco MT, Robinson M. A lean Six Sigma team increases hand hygiene compliance and reduces hospital-acquired MRSA infections by 51%. *J Healthc Qual*. 2010;32(4):61–70.
84. Yeung WK, Tam WS, Wong TW. Clustered randomized controlled trial of a hand hygiene intervention involving pocket-sized containers of alcohol-based hand rub for the control of infections in long-term care facilities. *Infect Control Hosp Epidemiol*. 2011;32(1):67–76.
85. Marra AR, Guastelli LR, de Araujo CM, dos Santos JL, Filho MA, Silva CV, et al. Positive deviance: a program for sustained improvement in hand hygiene compliance. *Am J Infect Control*. 2011;39(1):1–5.
86. Garcia-Vazquez E, Murcia-Paya J, Canteras M, Gomez J. Influence of a hygiene promotion programme on infection control in an intensive-care unit. *Clin Microbiol Infect*. 2011;17(6):894–900.
87. Kirkland KB, Homa KA, Lasky RA, Ptak JA, Taylor EA, Splaine ME. Impact of a hospital-wide hand hygiene initiative on healthcare-associated infections: results of an interrupted time series. *BMJ Qual Saf*. 2012;21(12):1019–26.
88. Mestre G, Berbel C, Tortajada P, Alarcia M, Coca R, Gallego G, et al. "The 3/3 strategy": a successful multifaceted hospital wide hand hygiene intervention based on WHO and continuous quality improvement methodology. *PLoS ONE*. 2012;7(10):e47200.
89. Talbot TR, Johnson JG, Ferguson C, Domenico JH, Schaffner W, Daniels TL, et al. Sustained improvement in hand hygiene adherence: utilizing shared accountability and financial incentives. *Infect Control Hosp Epidemiol*. 2013;34(11):1129–36.
90. Salama MF, Jamal WY, Mousa HA, Al-Abdulghani KA, Rotimi VO. The effect of hand hygiene compliance on hospital-acquired infections in an ICU setting in a Kuwaiti teaching hospital. *J Infect Public Health*. 2013;6(1):27–34.
91. Iacobelli S, Colomb B, Bonsante F, Astruc K, Ferdynus C, Bouthet MF, et al. Successful control of a Methicillin-resistant *Staphylococcus aureus* outbreak in a neonatal intensive care unit: a retrospective, before-after study. *BMC Infect Dis*. 2013;13:440.
92. Johnson L, Grueber S, Schlotzhauer C, Phillips E, Bullock P, Basnett J, et al. A multifactorial action plan improves hand hygiene adherence and significantly reduces central line-associated bloodstream infections. *Am J Infect Control*. 2014;42(11):1146–51.
93. Fox C, Wavra T, Drake DA, Mulligan D, Bennett YP, Nelson C, et al. Use of a patient hand hygiene protocol to reduce hospital-acquired infections and improve nurses' hand washing. *Am J Crit Care*. 2015;24(3):216–24.
94. Chun HK, Kim KM, Park HR. Effects of hand hygiene education and individual feedback on hand hygiene behaviour, MRSA acquisition rate and MRSA colonization pressure among intensive care unit nurses. *Int J Nurs Pract*. 2015;21(6):709–15.
95. Shabot MM, Chassin MR, France AC, Inurria J, Kendrick J, Schmaltz SP. Using the targeted solutions tool (R) to improve hand hygiene compliance is associated with decreased health care-associated infections. *Jt Comm J Qual Patient Saf*. 2016;42(1):6–17.
96. Ragusa R, Giorgianni G, Lupo L, Sciacca A, Rametta S, La Verde M, et al. Healthcare-associated *Clostridium difficile* infection: role of correct hand hygiene in cross-infection control. *J Prev Med Hyg*. 2018;59(2):E145–52.
97. Al-Tawfiq JA, Treble M, Abdrababali R, Okeahialam C, Khazindar S, Myers S. Using targeted solution tools as an initiative to improve hand hygiene: challenges and lessons learned. *Epidemiol Infect*. 2018;146(2):276–82.
98. De la Rosa-Zamboni D, Ochoa SA, Laris-Gonzalez A, Cruz-Cordova A, Escalona-Venegas G, Perez-Avendano G, et al. Everybody hands-on to avoid ESKAPE: effect of sustained hand hygiene compliance on healthcare-associated infections and multidrug resistance in a paediatric hospital. *J Med Microbiol*. 2018;67(12):1761–71.
99. Lenz AM, Andion E, Ruvinsky S, Aguirre C, Alvarez Parma J, Jorro F, et al. Impact of a program aimed at reducing catheter-related infections implemented in nine pediatric intensive care units in Argentina. *Arch Argent Pediatr*. 2018;116(2):93–7.
100. Ojanpera H, Kanste OI, Syrjala H. Hand-hygiene compliance by hospital staff and incidence of health-care-associated infections. Finland Bull World Health Organ. 2020;98(7):475–83.
101. 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(6):727–32.

102. 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(12):1923–8.
103. Ragonese B, Mularoni A, Valeri A, Campanella M, Corso B, Fazzina ML, et al. Reducing carbapenem-resistant enterobacteriaceae using the targeted solution tool: a quality improvement project. *J Nurs Care Qual*. 2023;38(1):47–54.
104. Swoboda SM, Earsing K, Strauss K, Lane S, Lipsky BA. Electronic monitoring and voice prompts improve hand hygiene and decrease nosocomial infections in an intermediate care unit. *Crit Care Med*. 2004;32:358–63.
105. Helms B, Dorval S, Laurent PS, Winter M. Improving hand hygiene compliance: a multidisciplinary approach. *Am J Infect Control*. 2010;38(7):572–4.
106. Knight N, Strait T, Anthony N, Lovell R, Norton HJ, Sautter R, et al. Clostridium difficile colitis: a retrospective study of incidence and severity before and after institution of an alcohol-based hand rub policy. *Am J Infect Control*. 2010;38(7):523–8.
107. Raschka S, Dempster L, Bryce E. Health economic evaluation of an infection prevention and control program: are quality and patient safety programs worth the investment? *Am J Infect Control*. 2013;41(9):773–7.
108. Schweon SJ, Edmonds SL, Kirk J, Rowland DY, Acosta C. Effectiveness of a comprehensive hand hygiene program for reduction of infection rates in a long-term care facility. *Am J Infect Control*. 2013;41(1):39–44.
109. Sickbert-Bennett EE, DiBiase LM, Willis TM, Wolak ES, Weber DJ, Rutala WA. Reduction of Healthcare-Associated Infections by Exceeding High Compliance with Hand Hygiene Practices. *Emerg Infect Dis*. 2016;22(9):1628–30.
110. 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(8):956–7.
111. 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 healthcare-associated infections. *Am J Infect Control*. 2018;46:1381–6.
112. 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(7):741–7.
113. 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.
114. 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(8):931–7.
115. Barrett RE, Fleiss N, Hansen C, Campbell MM, Rychalsky M, Murdzek C, et al. Reducing MRSA infection in a new NICU during the COVID-19 pandemic. *Pediatrics*. 2023;151(2):e2022057033.
116. World Health OWPS. A guide to the implementation of the WHO multimodal hand hygiene improvement strategy: World Health Organization; 2009. Available from: <https://apps.who.int/iris/handle/10665/70030>.
117. Lotfinejad N, Peters A, Tartari E, Fankhauser-Rodriguez C, Pires D, Pittet D. Hand hygiene in health care: 20 years of ongoing advances and perspectives. *Lancet Infect Dis*. 2021;21(8):e209–21.
118. International A. ASTM 2755. Standard test method for determining the bacteria-eliminating effectiveness of healthcare personnel hand rub formulations using hands of adults. West Conshohocken: ASTM International; 2015.
119. Normalisation CE. EN 1500. EN 1500 Chemical disinfectants and antiseptics: hygienic hand disinfection: test method and requirement (phase 2/step 2). Brussels: Comite Europeen de Normalisation; 2013.

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