# Hand Hygiene, an Update

John M. Boyce, MD

**KEYWORDS**

• Hand hygiene • Handwashing • Compliance • Monitoring • Infection prevention
• Cross-transmission • Healthcare-associated infections

**KEY POINTS**

- Hand hygiene by health care personnel is one of the most important measures for preventing health care–associated infections, but adherence rates and hand hygiene technique remain suboptimal.
- Alcohol-based hand rubs are the preferred method of hand hygiene in most clinical scenarios, are more effective and better tolerated than handwashing, and facilitate improved hand hygiene.
- Obtaining accurate estimates of hand hygiene adherence rates is challenging, and combining automated monitoring systems with direct observation is a promising strategy.

## BACKGROUND

Soap has been used for washing the hands and body since its cleansing properties were recognized by ancient Egyptian and Greek civilizations, and handwashing has been promoted for religious reasons for many years.[1] In the mid-1800s, the role of hand hygiene in the prevention of health care–associated infections (HAIs) (ie, puerperal fever) was first recognized by Oliver Wendell Holmes and by Ignaz Philip Semmelweis, who is considered to be the father hand hygiene.[2,3] In the early 1960s, Mortimer and colleagues[4] conducted a prospective-controlled trial that demonstrated that infants who were cared for by nurses who did not wash their hands after touching an index infant colonized with *Staphylococcus aureus* acquired the organism significantly more often and more rapidly than did infants cared for by nurses who washed their hands with hexachlorophene soap between contact with infants.[2]

Before 2002, handwashing by health care personnel (HCP) in the United States was performed almost exclusively using either non-antimicrobial or antimicrobial soap. Evaluation of alcohol-based hand rubs (ABHRs) as an alternative to soap and water handwashing began as early in the late 1970s, with their adoption in some European hospitals during the next 20 years.[5–7] However, the Centers for Disease Control and Prevention (CDC) guidelines on environmental control and handwashing published in 1985 recommended that alcohol-containing solutions only be used for hand hygiene

J.M. Boyce Consulting, LLC, 62 Sonoma Lane, Middletown, CT 06457, USA
*E-mail address:* jmboyce69@gmail.com

Infect Dis Clin N Am 35 (2021) 553–573
https://doi.org/10.1016/j.idc.2021.04.003 **id.theclinics.com**

in emergency settings where sinks were not available.[2] In the period 1997 to 2000, seminal publications by European investigators demonstrated the advantages of ABHRs,[6–9] which stimulated greater interest in their adoption in the United States.

## GUIDELINE DEVELOPMENT

In 2002, the HICPAC/SHEA/APIC/IDSA Guideline for Hand Hygiene in Healthcare Settings was published.[2] One of the major changes in the guideline was the recommendation that ABHRs be used as the preferred method of hand hygiene in most clinical scenarios (**Box 1**).[2] The recommendations were based on persistently poor handwashing compliance by HCP over a period of decades, and the advantages that ABHRs have over washing hands with soap and water. With input of more than 100 experts, the updated and more comprehensive World Health Organization (WHO) Guidelines on Hand Hygiene in Health Care were published in final form in 2009.[3] The WHO guideline also recommended ABHRs as the preferred method of hand hygiene.[3] The 2014 Society for Healthcare Epidemiology of America (SHEA)/Infectious Diseases Society of America (IDSA) Practice Recommendations on hand hygiene provide a concise set of updated recommendations, compared with the CDC and WHO guidelines, and identify areas requiring additional research.[10]

**Box 1**
**Centers for Disease Control and Prevention indications for hand hygiene**

A. When hands are visibly dirty or contaminated with proteinaceous material or visibly soiled with blood or other body fluids, wash hands with either a non-antimicrobial soap and water or an antimicrobial soap and water

B. If hands are not visibly soiled, use ABHRs for routinely decontaminating hands in all other clinical situations described as follows. Alternatively, wash hands with an antimicrobial soap and water in all clinical situations described as follows.

C. Decontaminate hands before having direct contact with patients

D. Decontaminate hands before donning sterile gloves when inserting a central intravascular catheter

E. Decontaminate hands before inserting indwelling urinary catheters, peripheral vascular catheters, or other invasive devices that do not require a surgical procedure

F. Decontaminate hands after contact with a patient's intact skin (eg, when taking a pulse or blood pressure, and lifting a patient)

G. Decontaminate hands after contact with body fluids or excretions, mucous membranes, nonintact skin, and wound dressings if hands are not visibly soiled

H. Decontaminate hands if moving from a contaminated body site to a clean body site during patient care

I. Decontaminate hands after contact with inanimate objects (including medical equipment) in the immediate vicinity of the patient

J. Decontaminate hands after removing gloves

K. Before eating and after using the restroom, wash hands with a non-antimicrobial soap and water or with an antimicrobial soap and water

*From* Boyce JM, Pittet D. Guideline for Hand Hygiene in Healthcare Settings. Recommendations of the Healthcare Infection Control Practices Advisory Committee and the HICPAC/SHEA/APIC/IDSA Hand Hygiene Task Force. Society for Healthcare Epidemiology of America/Association for Professionals in Infection Control/Infectious Diseases Society of America. MMWR Recomm Rep 2002;51 (RR-16):1-45.

The guidelines in **Box 1** and a recently published book dedicated to hand hygiene provide a wealth of information regarding the many facets of hand hygiene.[2,3,11] The purpose of this article was to review briefly the basic concepts of hand hygiene and to emphasize recent studies that add to our understanding of hand hygiene. Common hand hygiene terms are defined in **Table 1**.

## MICROBIOME OF HANDS

Two types of microorganisms comprise the normal flora of hands: transient flora and resident flora.[3] Transient flora, which are often acquired by HCP during contact with patients or environmental surfaces, colonize the superficial layers of the skin. They represent the microorganisms most commonly associated with HAIs, and are easier to remove from the skin by using an ABHR or washing hands. Common examples of transient flora include methicillin-resistant *S aureus* (MRSA), vancomycin-resistant enterococci, and multidrug-resistant gram-negative bacteria. Resident flora colonize the deeper layers of the skin, are less likely to cause infections, and are more resistant to removal. Early studies using standard culture-based methods revealed total bacterial counts ranging from $3.9 \times 10^4$ to $4.6 \times 10^5$ colony-forming units (CFU)/$cm^2$.[3] Cultures of fingertips using agar plate methods have yielded counts ranging from 0 to 300 CFU.[3] A recent study of 50 healthy women found an average of 5.85 $\log_{10}$ CFU (range 4.42–7.36) aerobic bacteria per hand, and an average of 6.12 $\log_{10}$ CFU of anaerobic bacteria per hand.[12]

Newer 16 S ribosomal RNA (rRNA) gene sequencing methods can identify microorganisms that are not detected using standard culture-based methods. As a result, culture-based methods significantly underestimate the diversity of bacterial

**Table 1**
**Definition of terms**

| Term | Definition |
|---|---|
| Plain soap | Detergent that does not contain antimicrobial agents, or contains such agents solely as preservatives |
| Antimicrobial soap | Detergent containing an antimicrobial agent in concentrations sufficient to inactivate or temporarily suppress the growth of microorganisms |
| ABHR (Alcohol-based hand sanitizer) | Alcohol-containing preparation (liquid, gel, foam) formulated for application to the hands for reducing the number of viable microorganisms on the hands |
| Hand hygiene | A general term that applies to either handwashing or application of an ABHR |
| Handwashing | Washing hands with either plain soap or antimicrobial soap, followed by rinsing with water and drying hands |
| Hand antisepsis | Application of either an ABHR or washing hands with an antimicrobial soap |
| Surgical scrub or surgical hand rub | Hand antisepsis performed preoperatively by surgical personnel to eliminate transient flora and reduce resident hand flora |

*Adapted from* Refs.[2,3]

communities on the hands.[12] One study cited by Edmonds-Wilson and colleagues[13] used 16 S rRNA sequencing methods and found an average of more than 150 bacterial species on the palms. Staphylococcaceae, Corynebacteriaceae, Propionibacteriaceae, and Streptococcaceae have been identified on the hands in most studies.[13] Viruses and fungi account for less than 20% of the hand microbiome.

Of interest, a study using 16 S rRNA sequencing of samples obtained before and after hand hygiene revealed (1) that the sampling methods could affect the results, (2) ABHR had no more effect on microbiome diversity than rinsing with water, and (3) skin hydration was a major variable affecting bacterial abundance and community composition.[12] Use of ABHR temporarily reduces the number of microbiota on the hands, without producing significant long-term changes in the hand microbiome.[12,14] Additional studies of the effects of different hand hygiene products should include a variety of HCP (nurses, physicians, and other personnel) involved in patient care in various health care settings.

## ROLE OF HANDS IN TRANSMISSION OF PATHOGENS

Transmission of health care–associated pathogens from one patient to another requires that the following sequence of events occur.[2]

1. Organisms present on the patient's skin or on an environmental surface must be transferred to the hands of a health care worker
2. Organisms must be capable of remaining viable for at least several minutes on the health care worker's hands
3. Hand hygiene technique is inadequate, or hand hygiene is performed with an inappropriate agent, or is omitted entirely
4. Contaminated hands of the health care worker must come in direct contact with another patient, or with an inanimate object that will come in direct contact with a patient

A patient's skin is frequently colonized with a variety of health care–associated pathogens, including multidrug-resistant organisms (MDROs),[15] and is the most common source of transient contamination of the hands of HCP. Environmental surfaces in patient rooms are also often contaminated with MDROs.[15,16] HCP frequently touch the skin of patients, potentially contaminated environmental surfaces near the patient, and their own body and clothing. For example, a study in which intensive care unit (ICU) personnel wore a head-mounted camera revealed that they had hand (or glove) contact with a surface an average of once every 4.2 seconds.[17] As a result, HCP frequently contaminate their hands with health care–associated pathogens.[2] Hands of HCP may also become contaminated with gram-negative bacteria dispersed from contaminated sinks.[18] A recent systematic review and meta-analysis revealed that the pooled prevalence of MDRO contamination of HCP hands ranged from 4% to 9%, with considerable variation for MRSA, vancomycin-resistant enterococci, and gram-negative bacteria, depending on the geographic area, method of sampling hands, and health care setting.[19] One study found that 5.5% to 6.5% of *S aureus* could be transferred from a heavily contaminated dry surface biofilm to the hands following a single touch, with subsequent transfer to other surfaces that were touched.[20] Although little is known about how many bacteria must be present on hands in order for cross-transmission to occur, Bellissimo-Rodrigues and colleagues[21] found that individuals whose hands were contaminated with more than 1 $\log_{10}$ *Escherichia coli* could transmit the organism to the hands of another person if their hands were in contact for 1 minute. Additional studies of the level of hand contamination required for cross-

transmission to occur are needed, and research using innovative surrogate markers such as viral DNA or silica nanoparticles are warranted to gain a better understanding of transmission patterns.[22,23]

## INDICATIONS FOR HAND HYGIENE

Hand hygiene guidelines published by the CDC and WHO, and SHEA/IDSA practice recommendations on hand hygiene have specified the clinical situations in which hand hygiene is indicated (see **Box 1**). Furthermore, the WHO guideline introduced the concept of "My 5 Moments for Hand Hygiene" (M5M)[3]:

- Moment 1: Before touching a patient
- Moment 2: Before a clean/aseptic procedure
- Moment 3: After a body fluid exposure risk
- Moment 4: After touching a patient
- Moment 5: After touching patient surroundings

This concept was designed to aid in educating HCP about when to perform hand hygiene and to provide a framework for monitoring hand hygiene compliance.

## HAND HYGIENE PRODUCTS

### *Alcohol-Based Hand Rubs*

Compared with handwashing with soap and water, ABHRs have the following advantages[6,7]:

- More effective than soap and water in reducing viable organisms on the hands.
- Excellent activity against a broad range of pathogens (except spores), with somewhat less activity against some nonenveloped viruses
- Require much less time than washing hands with soap and water, rinsing, and drying
- Cause less skin irritation and dryness than frequent use of soap and water
- Unlike handwashing sinks, can be made available at the bedside and in many other locations
- Have been associated with improved compliance with hand hygiene

#### *Product format*

ABHR products are available in several formats, including liquids (with consistency similar to water), gels, and foams. All product formats are appropriate for use in health care settings, because product format does not significantly affect antimicrobial efficacy.[24,25] Liquid products with higher alcohol concentrations dry faster, but tend to drip more onto clothing or floors. Currently, alcohol-based wipes are not recommended for HCP hand hygiene in health care settings.[2,3,26]

#### *Formulation issues*

The concentration of alcohol in ABHRs does not significantly affect efficacy, as evidenced by the fact that some products formulated with 70% ethanol are more efficacious than products with higher ethanol concentrations.[27] This can be explained by the manner in which products are formulated, and the types of other constituents included. Not surprisingly, the greater the volume of product applied to the hands, the longer hands must be rubbed together before they feel dry (dry-time).[24,25,28] The major factor affecting antimicrobial efficacy is the dry-time, with longer dry-times leading to greater efficacy.[28]

The antimicrobial efficacy of ABHRs depends on other factors as well, including the test methods used, the alcohol tested, the presence of other constituents (product formulation), and the volume applied.[24,25,27-29] For example, one in vivo study that applied 2 mL of 11 different products to hands found that mean $\log_{10}$ reductions after a single application varied from 2.48 to 3.58.[27] In another study that applied a volume more typically delivered by dispensers (1.1 mL) to hands, the mean $\log_{10}$ reduction after a single application was 2.85.[30] Although the CDC and WHO hand hygiene guidelines recommended using a product with persistent or sustained activity for surgical hand antisepsis, the WHO 2016 Guideline on Prevention of Surgical Site Infections did not make a recommendation on whether or not products for surgical hand antisepsis need to have sustained activity.[31] Of note, recent studies have confirmed the efficacy of ABHRs against severe acute respiratory syndrome coronavirus 2.[32,33]

***Safety of alcohol-based hand rubs***

ABHRs are safe and effective when used as directed. Adverse events related to ingestion by in-patients have rarely been reported. Restricting access to ABHRs by patients with psychiatric or dementia problems seems prudent, and is commonly practiced in health care facilities. Depending on the facility, this may be accomplished by placing dispensers in areas not accessible to patients, or by providing personnel with pocket bottles. Because some nurses may perform hand hygiene with ABHRs more than 100 times per 12-hour shift,[34] the Food and Drug Administration (FDA) has mandated that industry conduct a "maximum-use trial" to confirm the safety of very frequent use of ABHRs. During the Coronavirus Disease 2019 (COVID-19) pandemic, worldwide shortages of ABHRs resulted in production of ABHRs by some distilleries and by companies that did not follow good manufacturing processes. Episodes of methanol toxicity related to poorly formulated products produced outside the United States have been reported,[35] and resulted in the FDA issuing warnings to avoid some products produced in Mexico.

***Delivery systems***

ABHRs are made available in manual and touch-free wall-mounted dispensers, free-standing pump bottles, and pocket bottles. Although some HCP have expressed concern about contaminating their hands by touching manual wall-mounted dispensers or pocket bottles, there is no evidence that touching such items has resulted in transmission of pathogens. Any microorganisms that might be transferred from the dispenser or bottle to hands are immediately reduced significantly by application of the hand rub. To maximize the use of ABHRs, wall-mounted dispensers should be placed in hallways near the doors of patient rooms in addition to having dispensers at bedsides or within a few feet of patient beds. Several studies have shown that HCP use dispensers located in hallways more frequently than those in patient rooms.[36,37] However, some personnel may be more likely to access bedside dispensers during invasive procedures or patient care that may expose personnel to a patient's body fluids or excretions.[36] Dispensers should be placed in locations that are in the line-of-sight of personnel and are consistent with workflow patterns.[38] Dispensers also should be available in perioperative areas, because surgical hand antisepsis can be performed with either an antimicrobial soap and water or an alcohol-based hand rub.[2,3]

## *Non–Alcohol-based Hand Rubs*

Although a number of non-ABHRs have been marketed, current guidelines do not recommend the use of nonalcohol hand rubs for routine hand hygiene in health care

settings.[2,3,39] Additional studies of such products are needed to establish their antimicrobial efficacy, impact on transmission of pathogens, and ability to reduce HAIs.

### *Soap*

Soaps can help remove dirt, proteinaceous material, and some microorganisms from hands via mechanical action. Plain soaps have little or no antimicrobial activity. Washing hands with plain soap and water is less effective than performing hand hygiene with an ABHR.[2,3] Early studies reported that washing hands with plain soap and water for 15 seconds reduced bacteria on the hands by 0.6 to 1.1 $\log_{10}$, and washing for 30 seconds reduced bacteria by 1.8 to 2.8 $\log_{10}$.[2] A recent study of washing nonwetted hands for 30 seconds with a novel non-antimicrobial soap compared with washing with the standard plain soap reported $\log_{10}$ reductions of 1.46 and 1.12, respectively.[40] Interestingly, if soap was applied after hands were wetted, lower $\log_{10}$ reductions of 1.07 and 0.97, respectively, were achieved. In real-life clinical situations, $\log_{10}$ reductions achieved may be lower than those observed in laboratory studies because most HCP wash their hands for less than 15 seconds.[2] Washing hands with an antimicrobial soap is generally more effective than washing with plain soap, but less effective than performing hand hygiene with an alcohol-based hand rub.[2,3] Washing hands with hot water should be avoided, as it has no significant effect on antimicrobial efficacy, and can increase the risk of hand dermatitis.

## GLOVES

Gloves help reduce, but do not eliminate, contamination of the hands of HCP that can occur when touching patients or their environment. Gloves represent the primary form of hand hygiene when caring for patients with *Clostridioides difficile* infection because ABHRs are not effective in reducing spores from hands. In routine or endemic settings, hand hygiene after caring for patients with *C difficile* infection can be performed after removing gloves with either soap and water or an alcohol-based hand rub.[41] If *C difficile* infections are epidemic or hyperendemic, handwashing with soap and water is the preferred method. Hand hygiene is always recommended after removing gloves, because gloves do not protect completely against hand contamination.[2] Although HCP frequently perform hand hygiene before donning nonsterile gloves, the need for this is somewhat controversial. A randomized controlled trial found that hand hygiene before donning nonsterile gloves did not significantly reduce bacterial counts on gloves,[42] suggesting that this issue requires reconsideration. If glove changes are indicated during an episode of care on the same patient, hand hygiene should be performed after removing gloves and before donning a new pair of nonsterile gloves.

## HAND HYGIENE TECHNIQUE

Following publication of the CDC and WHO guidelines, most efforts to promote improved hand hygiene have focused on increasing hand hygiene compliance, with little attention paid to how hand hygiene is performed (hand hygiene technique). As an example, several studies have reported that high adherence rates were accompanied by poor hand hygiene technique.[43,44] Because approximately 80% of hand hygiene events are performed using ABHR,[36,45,46] studies of hand hygiene technique have focused on the use of ABHRs.

Factors affecting the adequacy of hand hygiene technique include the extent to which personnel cover all surfaces of their hands and fingers with ABHR, the volume of product applied, the duration of hand rubbing (dry-time), and hand size. Personnel often do not adequately apply hand rub to their fingertips and thumbs.[47] The WHO 6-

step hand hygiene protocol was designed to ensure coverage of all surfaces of hands, but compliance with the protocol is often suboptimal.[48] As a result, modifications of the WHO protocol have recently been described.[49] A greatly simplified procedure was developed that includes the following 3 steps: (1) cover all surfaces of the hand, (2) rotational rubbing of fingertips in the palm of the alternate hand, and (3) rotational rubbing of both thumbs (**Fig. 1**).[49] A cluster randomized trial comparing the simplified 3-step protocol with the 6-step WHO protocol revealed that the simplified method resulted in increased compliance, and was not microbiologically inferior to the WHO 6-step protocol.[44]

Inadequate coverage also may occur when personnel apply a small volume of ABHR to their hands to achieve short dry-times, which are often <15 seconds.[17,43,50] However, current studies suggest that dry-times of 15 seconds or longer should be applied to achieve desired reductions of pathogens.[51–53] Because applying volumes of less than 1 mL often results in dry-times of less than 15 seconds,[25,30,54] facilities should consider adjusting ABHR dispensers to deliver a minimum of 1 mL of product with one accession. Educating personnel about the importance of applying an amount of ABHR that yields adequate dry-times should be part of hand hygiene promotion programs.

Not surprisingly, hand size can also affect how well surfaces are covered and dry-times achieved with ABHRs.[28] When a given dose is applied to large hands, dry-times are shorter than when applied to small hands.[28] As a result, it has been suggested that dosing should be individualized to achieve adequate dry-times.[28] However, when nurses are given the opportunity to choose the dose they receive, those with large

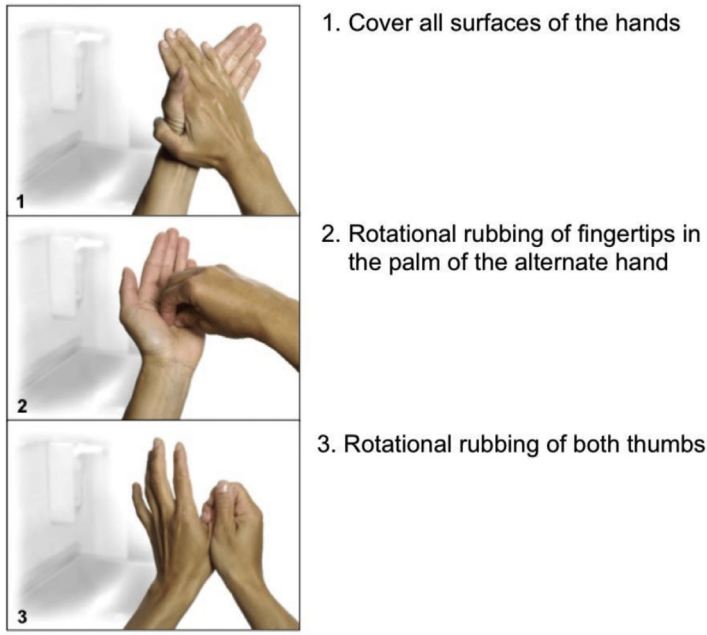


**Fig. 1.** Simplified 3-step hand hygiene technique. (*From* Tschudin-Sutter S, Rotter ML, Frei R, Nogarth D, Hausermann P, Stranden A, Pittet D, Widmer AF. Simplifying the WHO 'how to hand rub' technique: three steps are as effective as sixdresults from an experimental randomized crossover trial. Clin Microbiol Infect 2017;23:409.e1- 409.e4; with permission.)

hands may not select larger doses than those with small hands.[55] Individualizing doses might be facilitated in the future if dispensers could deliver variable amounts based on an individual's hand size.

CDC guideline recommends that when washing hands with soap and water, personnel should first wet hands with water, apply an amount of soap recommended by the manufacturer, and rub hands together vigorously for at least 15 seconds, covering all surfaces of the hands and fingers.[2] Hands should then be rinsed with water and dried thoroughly with a disposable towel. The WHO guideline recommends wetting hands before applying an amount of soap necessary to cover all surfaces followed by rinsing hands with water and drying thoroughly with a single-use towel.[3] The duration of the entire process should be 40 to 60 seconds. Although some investigators have recommended against the use of jet-air electric dryers in hospitals,[56] further research is needed to establish with certainty the safest method for drying hands in health care settings.[57]

## HAND HYGIENE ADHERENCE

Before publication of the CDC and WHO guidelines, HCP hand hygiene adherence rates averaged approximately 40%.[2,3] Hand hygiene adherence rates have improved in the ensuing years, although achieving and sustaining high rates of adherence remain challenges in many facilities. Reported adherence rates have varied tremendously, from less than 25% to more than 90%, depending on the country, health care setting (hospital vs long-term care facility), hospital bed size, type of nursing unit, HCP job category, indication for hand hygiene, promotional interventions, and methods used to estimate adherence rates (direct observation methods vs automated monitoring systems).[17,44–46,48,50,58–74] Due to the large number of factors affecting adherence rates, a comprehensive analysis of the topic is beyond the scope of this review. Accordingly, only a few factors are mentioned here.

Lambe and colleagues[61] found that adherence rates in ICUs were lower in low-income countries than in high-income countries. A study involving 5 acute-care hospitals revealed that adherence rates decreased as hospital bed size increased.[66] Several studies documented very low adherence rates in nursing homes.[62,63] In 1 of the 2 studies that was conducted in the United States, HCP performed hand hygiene more frequently with soap and water than with ABHR,[62] an issue that likely persists in some other nursing homes. Within a given facility, there is substantial individual variability in adherence rates,[37,75,76] with adherence by physicians often (but not always) lower than among nurses.[50,58,61,64,67] Adherence rates continue to vary depending on the type of patient care being provided, with personnel performing hand hygiene more frequently after patient contact (to protect themselves) than before contact (to protect patients).[37,62–64] In the context of the M5M; adherence to Moments 1 and 2 is sometimes lower than it is to Moments 3, 4, and 5.[50,61,77] As a result, ongoing efforts to improve adherence need to focus on reminding personnel of the importance of performing hand hygiene before touching patients and before performing aseptic procedures.

## MONITORING HAND HYGIENE ADHERENCE

### *Direct Observation Method*

Monitoring adherence to hand hygiene recommendations by HCP and providing them with feedback regarding their performance are essential elements of an effective multimodal strategy for improving hand hygiene.[2,3] Unfortunately, monitoring hand hygiene adherence has proven to be more complex than anticipated, and remains a

challenge in many health care facilities. Direct observation of personnel by trained observers is by far the most common method for estimating adherence rates, and continues to be considered the "gold standard" method.

Advantages and disadvantages of the direct observation method are summarized in **Box 2**. Unlike other methods, direct observations can be used to monitor all M5M, although this may prove difficult in some settings.[64] Hand hygiene technique can be evaluated, although this is seldom recorded and analyzed. Unlike currently available automated monitoring systems, direct observations are feasible in virtually all types of health care facilities, including those with few resources.

The accuracy of hand hygiene adherence rates generated by direct observations is affected by multiple factors.[78,79] Despite some guidance provided by the WHO guidelines, there is a lack of standardization of the following factors: the type and time spent training of observers, the frequency of validating interobserver reliability, the type of personnel performing observations, the criteria for hand hygiene adherence (hand hygiene on room entry and exit, the M5M, 4 Moments for Hand Hygiene [eg, Canada]), and the duration of the observation sessions (range, 10 minutes to >1 hour).[70,73,80,81] Many hospitals in the United States observe hand hygiene adherence of personnel on room entry and room exit, whereas others monitor adherence to the M5M.[80] Monitoring personnel at room entry and exit is popular because it is easier to perform than attempting to observe all M5M. Covertly observing M5M, especially Moments 2 and 3, can be difficult due to privacy curtains being drawn or to architectural aspects of the nursing unit.[64] One comparative study found that adherence rates generated by the 2 methods were similar, whereas another study found that monitoring M5M resulted in significantly higher adherence rates than observing room entries and exits.[64,82] A review of 28 studies found that adherence rates for Moments 1, 4, and 5 combined were similar to rates for all M5M.[78]

Many hospitals perform observations only during day shifts during weekdays, and may observe as few as 10 to 30 hand hygiene opportunities/nursing unit/month.[80,81,83] However, the number of hand hygiene opportunities often varies from 10,000 to greater than 100,000/unit/month on medical and surgical wards, and from 20,000 to 150,000/unit/month in ICUs.[50,81,84–87] As a result, in many hospitals, direct observations often capture as few as $\leq$0.1% of all hand hygiene opportunities,[73,81,83,88] which is too small a sample to yield valid results. The WHO Hand Hygiene Implementation

**Box 2**
**Advantages and disadvantages of monitoring hand hygiene using the direct observation method**

Advantages
- Ability to estimate adherence with all "My 5 Moments for Hand Hygiene"
- Identify barriers to hand hygiene
- Evaluation of hand hygiene technique
- Most widely used method for monitoring adherence
- Applicable in virtually all facilities, regardless of the level of resources

Disadvantages
- Lack of standardized methods for training observers and conducting auditing sessions
- Periodic validation of observer accuracy is often not performed
- Inadequate sampling of hand hygiene opportunities
- Hawthorne effect results in exaggerated adherence rates
- Observing all indications for hand hygiene is difficult in some settings
- Conducting observations is time consuming
- Observers and frontline staff may have concerns regarding the accuracy of results

Guide and an analysis by Yin and colleagues[89] recommend that hospitals observe 150 to 200 hand hygiene opportunities/nursing unit/time period to obtain reasonable estimates of adherence rates.[90]

The Hawthorne effect is common with direct observation method, and varies with the type of observer, the presence of nearby HCP not involved in performing observations, and the duration of the observation sessions.[86,89,91–94] Adherence rates are higher when generated by unit-based observers than by non–unit-based observers, and when other HCP are nearby.[86,91] The Hawthorne effect increases significantly when observation periods are more than 15 minutes in duration.[89,92,94] As a result of the preceding issues, adherence rates generated by direct observations are 1.5-fold to 3-fold higher than those generated by automated monitoring systems.[60,77,95] Although some infection preventionists assume that the Hawthorne effect has a positive, long-term effect on adherence rates, 2 studies have found that increased adherence rates associated with the Hawthorne decrease by 50% to 100% within 1 hour after the observer has left the unit.[96,97] Overall, the lack of standardized methods for conducting direct observations precludes comparing rates between institutions.

Tips on how to optimize direct observations include the following:

- Provide observers with standardized training, including videos if possible
- Periodically validate observer accuracy
- Reduce impact of Hawthorne effect:
  - Use covert "secret shopper" observers
  - Avoid observers performing audits on their own units
  - Avoid having observers who collect adherence data provide immediate feedback
  - Have champions limit activities to coaching and promotional efforts
- If possible, observe ~150 to 200 opportunities/unit/time period, unless unit is small
- Consider using a digital app for recording observations, to facilitate processing data
- Monitor hand hygiene technique
  - Observe if ABHR is applied to all surfaces of hands (including thumbs and fingertips)
  - Monitor duration of hand rubs (should be $\geq$15 seconds of rubbing)

### *Automated Hand Hygiene Monitoring*

Electronic counting devices installed in dispensers can record many more hand hygiene events (HHEs) than direct observations, and can be used to monitor trends in hand hygiene frequency, but do not provide adherence data.[78,98]

#### *Group monitoring systems*

Several group monitoring systems are available that estimate unit-level HCP adherence rates. One system uses dispensers equipped with sensors that record each accession (HHEs) and send data to a central server. Hand hygiene opportunities (HHOs) are estimated using a software algorithm based on initial observations of the distribution of M5M (or M4M) on different units, patient census, patient-to-nurse ratios, and adjustments.[69,99–101] Estimated adherence rates are calculated by dividing the number of HHEs by the estimated number of HHOs. Studies have validated the approach to estimating HHOs in several settings.[36,85,100,102] However, some facilities may encounter challenges in obtaining accurate census and staffing data.[103] Advantages of the system include its estimates of adherence with all M5M (or M4M), and a lack of need for sensors at patient doorways or specialized

personnel badges. A recent 2-year stepped-wedge cluster randomized study conducted in 5 hospitals documented a significant overall improvement in hand hygiene adherence, from a baseline level of 29% to 53% after 10 months, and a trend toward reduced transmission of MRSA.[69] Importantly, system implementation was accompanied by multiple complementary measures, including several methods of providing HCP with feedback and encouraging accountability.

Other group "activity" monitoring systems use sensors in dispensers and at doorways to patient rooms to monitor each room entry and exit, which are considered HHOs.[83,87,104] Some systems can provide audible reminders on room entry and exit.[87] Compared with direct observations, advantages include the following:

- Capture 100 to greater than 10,000 times as many HHOs on a 24/7 basis compared to the number of direct observations performed per time period in many facilities
- Provide large amounts of data on estimated adherence rates
- Not affected by observer bias and Hawthorne effect
- Provide near real-time feedback on unit-level adherence rates
- Require much less personnel time than direct observation
- Perceived as less intrusive than badge-based systems
- Less expensive than badge-based systems

One group activity monitoring system also documented changes in room entry/exit frequency and adherence rates related to the COVID-19 pandemic.[105] One system reported to have a sensitivity of 92.7% and positive predictive value of 84.4% has been associated with significantly increased hand hygiene adherence in 2 studies (Abstract: Landon E et al. Open Forum Infect Dis 2017;4 (Suppl 1):S408).[83,104] In one study, implementing the system was associated with a trend toward fewer non–*C difficile* HAIs.[83]

Limitations of activity monitoring systems include their inability to differentiate visitors from HCP entering and exiting rooms, lack of individual-specific adherence rates, and limited published evidence regarding their ability to sustain improved hand hygiene performance and to reduce health care–associated infections.[78] Data on the relative frequency of room entries and exits by HCP and visitors are available,[106] and can be used to adjust estimated adherence rates.

***Badge-based systems***

Badge-based automated systems include sensors located in dispensers, patient rooms, and specialized electronic personnel badges.[78] These systems can detect entry of individual HCP into patient rooms, whether or not hand hygiene was performed just before or after entering the room, and provide individual feedback in a variety of forms.[71,72,74,81,88,107] Of the badge-based systems whose accuracy has been formally validated, one had an accuracy of 99%, and another correctly identified ~85% of HHOs.[73,107] Adherence rates have ranged from approximately 63% to 85% to 95%, with the highest rates more common in those with immediate reminder functions.[46,71,72,74,75,81,88] Additional advantages include the ability to identify significant variability in individual performance, the impact of duration of room visit on adherence rates, identify consecutive missed opportunities, and analyze the frequency of room visits by individuals, which may aid in outbreak investigations and contact tracing.[75,107] Limitations include the installation and maintenance costs of such systems, limited evidence on their cost-effectiveness, ability to yield long-term improvements in adherence rates, and HAI rates, accuracy and badge-related issues with some systems, and level of acceptance by HCP.[71,72,108,109]

***Systems based on video cameras or other technologies***

Few studies have evaluated the use of video cameras to evaluate hand hygiene adherence.[17,93,110–112] Implementation of a video camera system in a single institution achieved sustained adherence rates of ~80% in a medical ICU and surgical ICU.[111,112] Further research of video-based systems is needed to address concerns regarding personnel and patient privacy, cost-effectiveness, and impact on HAIs. Using machine learning and neural network techniques to combine computer vision with data from depth and thermal sensors shows promise for providing new approaches to automated hand hygiene monitoring.[113]

***Importance of complementary strategies***

A point that cannot be overemphasized is the need for automated hand hygiene monitoring systems to be incorporated into a multimodal promotion program.[69,71,73,76,83,114] Implementation plans should include validation of the system by hospital personnel using a 2-phase protocol.[104,108,115] Installing an automated system without implementing complementary strategies is very likely to lead to little or no improvement in adherence rates (Abstract: Edmonds-Wilson S et al. Am J Infect Control 2016;44(6):S6-7).[83] Hospitals that have successfully implemented automated monitoring systems have used a variety of complementary strategies, examples of which are available as abstracts (Abstract: Landon E et al. Open Forum Infect Dis 2017;4 (Suppl 1):S408; Abstract: Arbogast J et al. Infect Control Hosp Epidemiol 2020;41 (Suppl 1):S451-2), and others in full-length articles.[69,71,73,81,83,110,116]

- Engagement of hospital leadership
- Input of frontline staff before implementation regarding workflow patterns and concerns
- Interacting with system vendor during and after installation
- Weekly adherence reports e-mailed to department and unit managers
- Weekly feedback via emails or text messages to individuals when using badge-based system, which may include anonymized rates of other individuals in similar job positions
- Unit managers and champions attend weekly “accountability” meetings/calls to share adherence rates, challenges, and successful local initiatives
- Posting weekly unit-based adherence rates in areas visible to personnel and patients
- Recognition of top performers, and prize for top performer
- Periodic educational rounds or in-house webinars

***Personnel attitudes toward automated monitoring***

Before and during early phases of implementation, HCP may harbor concerns regarding the accuracy of automated systems, and have fears of potential punitive consequences.[117] It is essential to (1) explain to personnel in advance about how the systems work and their limitations, (2) alert personnel to expect lower adherence rates than those based on direct observations, and (3) be transparent about how adherence data will be used.[69,73,83,103,117,118]

***Combining automated monitoring with direct observation***

As additional information regarding the accuracy and effectiveness of automated systems becomes available, hospitals may want to consider combining automated monitoring with direction observations.[78] For example:

- Use automated systems as the primary source of quantitative data on adherence rates and feedback mechanisms

- Use direct observations for scenarios in which it has unique advantages
  - Monitor adherence to Moments 2 and 3
  - Evaluate adherence with performing hand hygiene between multiple tasks during an episode of care with the same patient
  - Monitor hand hygiene technique
    - Is ABHR applied to all surfaces of the hands (especially fingertips and thumbs)?
    - Are hands rubbed together for at least 15 seconds?

## IMPACT OF HAND HYGIENE ON HEALTH CARE–ASSOCIATED INFECTIONS

Multiple studies have shown that improving hand hygiene can reduce HAIs.[3,9,70,119] A smaller number of studies have reported that automated monitoring systems have been associated with reductions in HAIs.[69,73,81,83,114,116] Additional studies are needed to determine the ability of different forms of automated monitoring to reduce HAIs.

## ISSUES REQUIRING ADDITIONAL RESEARCH

Important aspects of hand hygiene not included in the present review include the role of patient hand hygiene in reducing HAIs, and improving adherence rates in long-term care facilities, outpatient hemodialysis centers, clinics, and dental facilities. Other issues that require additional research include (but are not limited to) the level of hand contamination needed to prevent pathogen transmission, optimum hand hygiene technique, and the most effective methods for providing personnel with feedback regarding their performance.

## CLINICS CARE POINTS

- Perform hand hygiene before touching patients or performing aseptic procedures to reduce the chances of transmitting health care–associated pathogens to your patients.
- If an adequate amount of ABHR was applied to your hands, it should require rubbing your hands together for 15 seconds or longer before they feel dry.
- During a work shift, do not switch frequently between an ABHR and washing with soap and water, as this increases the risk of hand irritation. Wash only when indicated.
- Routinely wear gloves when caring for patients with *C difficile* infection.
- Always perform hand hygiene after removing gloves.

## DISCLOSURE

J.M. Boyce is a consultant to, has received travel support from, and has presented at conference symposia sponsored by Diversey and by GOJO Industries, and is a consultant to Sodexo Healthcare.

## REFERENCES

1. Vermeil T, Peters A, Kilpatrick C, et al. Hand hygiene in hospitals: anatomy of a revolution. J Hosp Infect 2019;101(4):383–92.
2. Boyce JM, Pittet D. Guideline for hand hygiene in health-care settings: recommendations of the healthcare infection control practices advisory committee and the HICPAC/SHEA/APIC/IDSA hand hygiene task force. Infect Control Hosp Epidemiol 2002;23(12 Suppl):S3–40.

3. World Health O. WHO guidelines for hand hygiene in health care. Geneva: World Health Organization; 2009.
4. Mortimer EA Jr, Lipsitz PJ, Wolinsky E, et al. Transmission of staphylococci between newborns. Am J Dis Child 1962;104:289–95.
5. Ayliffe GA, Babb JR, Quoraishi AH. A test for 'hygienic' hand disinfection. J Clin Pathol 1978;31(10):923–8.
6. Widmer AF. Replace hand washing with use of a waterless alcohol hand rub? Clin Infect Dis 2000;31:136–43.
7. Rotter M. Arguments for the alcoholic hand disinfection. J Hosp Infect 2001; 28(Suppl A):S4–8.
8. Voss A, Widmer AF. No time for handwashing!? Handwashing versus alcoholic rub: can we afford 100% compliance? Infect Control Hosp Epidemiol 1997;18: 205–8.
9. Pittet D, Hugonnet S, Harbarth S, et al. Effectiveness of a hospital-wide programme to improve compliance with hand hygiene. Lancet 2000;356:1307–12.
10. Ellingson K, Haas JP, Aiello AE, et al. Strategies to prevent healthcare-associated infections through hand hygiene. Infect Control Hosp Epidemiol 2014;35(Suppl 2):S155–78.
11. Hand hygiene: a handbook for medical professionals. Hoboken, NJ: Wiley-Blackwell; 2017.
12. Zapka C, Leff J, Henley J, et al. Comparison of standard culture-based method to culture-independent method for evaluation of hygiene effects on the hand microbiome. mBio 2017;8(2):e00093.
13. Edmonds-Wilson SL, Nurinova NI, Zapka CA, et al. Review of human hand microbiome research. J Dermatol Sci 2015;80(1):3–12.
14. Mukherjee PK, Chandra J, Retuerto M, et al. Effect of alcohol-based hand rub on hand microbiome and hand skin health in hospitalized adult stem cell transplant patients: A pilot study. J Am Acad Dermatol 2018;78(6):1218–21.e5.
15. Mody L, Washer LL, Kaye KS, et al. Multidrug-resistant organisms in hospitals: what is on patient hands and in their rooms? Clin Infect Dis 2019;69(11): 1837–44.
16. Shams AM, Rose LJ, Edwards JR, et al. Assessment of the overall and multidrug-resistant organism bioburden on environmental surfaces in healthcare facilities. Infect Control Hosp Epidemiol 2016;37(12):1426–32.
17. Clack L, Scotoni M, Wolfensberger A, et al. "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.
18. Hajar Z, Mana TSC, Cadnum JL, et al. Dispersal of gram-negative bacilli from contaminated sink drains to cover gowns and hands during hand washing. Infect Control Hosp Epidemiol 2019;40(4):460–2.
19. Montoya A, Schildhouse R, Goyal A, et al. How often are health care personnel hands colonized with multidrug- resistant organisms? A systematic review and meta-analysis. Am J Infect Control 2019;47(6):693–703.
20. Chowdhury D, Tahir S, Legge M, et al. Transfer of dry surface biofilm in the healthcare environment: the role of healthcare workers' hands as vehicles. J Hosp Infect 2018;100(3):e85–90.
21. Bellissimo-Rodrigues F, Pires D, Soule H, et al. Assessing the likelihood of hand-to-hand cross-transmission of bacteria: an experimental study. Infect Control Hosp Epidemiol 2017;38(5):553–8.

22. Thakur M, Alhmidi H, Cadnum JL, et al. Use of viral DNA surrogate markers to study routes of transmission of healthcare-associated pathogens. Infect Control Hosp Epidemiol 2020;1–6.
23. Scotoni M, Koch J, Julian TR, et al. Silica nanoparticles with encapsulated DNA (SPED) - a novel surrogate tracer for microbial transmission in healthcare. Antimicrob Resist Infect Control 2020;9(1):152.
24. Wilkinson MAC, Ormandy K, Bradley CR, et al. 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.
25. Macinga DR, Shumaker DJ, Werner HP, 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.
26. Ory J, Zingg W, de Kraker MEA, et al. Wiping is inferior to rubbing: a note of caution for hand hygiene with alcohol-based solutions. Infect Control Hosp Epidemiol 2018;39(3):332–5.
27. Edmonds SL, Macinga DR, Mays-Suko P, 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.
28. Suchomel M, Leslie RA, Parker AE, et al. 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.
29. Macinga DR, Edmonds SL, Campbell E, et al. Efficacy of novel alcohol-based hand rub products at typical in-use volumes. Infect Control Hosp Epidemiol 2013;34(3):299–301.
30. World Health Organization. Global guidelines on the prevention of surgical site infections. Geneva (Switzerland): WHO Press, World Health Organization; 2016.
31. World Health O. Global guidelines on the prevention of surgical site infection 2017.
32. Kratzel A, Todt D, V'Kovski P, et al. Inactivation of severe acute respiratory syndrome coronavirus 2 by WHO-recommended hand rub formulations and alcohols. Emerg Infect Dis 2020;26(7):1592–5.
33. Leslie RA, Zhou SS, Macinga DR. Inactivation of SARS-CoV-2 by commercially available alcohol-based hand sanitizers. Am J Infect Control 2012;49:401–2.
34. Boyce JM, Polgreen PM, Monsalve M, et al. Frequency of use of alcohol-based hand rubs by nurses: a systematic review. Infect Control Hosp Epidemiol 2017;38(2):189–95.
35. Dear K, Grayson L, Nixon R. Potential methanol toxicity and the importance of using a standardised alcohol-based hand rub formulation in the era of COVID-19. Antimicrob Resist Infect Control 2020;9(1):129.
36. Conway L, Moore C, Coleman BL, et al. Frequency of hand hygiene opportunities in patients on a general surgery service. Am J Infect Control 2020;48(5):490–5.
37. Iversen AM, Kavalaris CP, Hansen R, et al. Clinical experiences with a new system for automated hand hygiene monitoring: a prospective observational study. Am J Infect Control 2020;48(5):527–33.
38. Pennathur PR, Herwaldt LA. Role of human factors engineering in infection prevention: gaps and opportunities. Curr Treat Options Infect Dis 2017;9(2):230–49.
39. la Fleur P, Jones S. Non-alcohol based hand rubs: a review of clinical effectiveness and guidelines [Internet] 2017. Available at: https://ncbi.nlm.nih.gov/books/NBK470501. Accessed January 14, 2021.

40. Bingham J, Cartner TJ, Mays Suko PA, et al. Multifactor assessment of non-antimicrobial soap performance. Open Forum Infect Dis 2019;6(5):ofz151.
41. McDonald LC, Gerding DN, Johnson S, et al. Clinical practice guidelines for clostridium difficile infection in adults and children: 2017 update by the Infectious Diseases Society of America (IDSA) and Society for Healthcare Epidemiology of America (SHEA). Clin Infect Dis 2018;66(7):987–94.
42. Rock C, Harris AD, Reich NG, et al. Is hand hygiene before putting on nonsterile gloves in the intensive care unit a waste of health care worker time?–a randomized controlled trial. Am J Infect Control 2013;41(11):994–6.
43. Helder OK, Brug J, Looman CW, et al. 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.
44. Tschudin-Sutter S, Sepulcri D, Dangel M, et al. Simplifying the WHO protocol: Three steps versus six steps for performance of hand hygiene - a cluster-randomized trial. Clin Infect Dis 2019;69:614–20.
45. Stewardson AJ, Sax H, Gayet-Ageron A, et al. Enhanced performance feedback and patient participation to improve hand hygiene compliance of health-care workers in the setting of established multimodal promotion: a single-centre, cluster randomised controlled trial. Lancet Infect Dis 2016;16(12):1345–55.
46. Albright J, White B, Pedersen D, et al. Use patterns and frequency of hand hygiene in healthcare facilities: analysis of electronic surveillance data. Am J Infect Control 2018;46:1104–9.
47. Widmer AF, Dangel M. Alcohol-based handrub: evaluation of technique and microbiological efficacy with international infection control professionals. Infect Control Hosp Epidemiol 2004;25(3):207–9.
48. Tschudin-Sutter S, Sepulcri D, Dangel M, et al. Compliance with the World Health Organization hand hygiene technique: a prospective observational study. Infect Control Hosp Epidemiol 2015;36(4):482–3.
49. Tschudin-Sutter S, Rotter ML, Frei R, et al. Simplifying the WHO 'how to hand rub' technique: three steps are as effective as six-results from an experimental randomized crossover trial. Clin Microbiol Infect 2017;23(6):409.
50. Stahmeyer JT, Lutze B, von LT, et al. Hand hygiene in intensive care units: a matter of time? J Hosp Infect 2017;95(4):338–43.
51. Pires D, Soule H, Bellissimo-Rodrigues F, et al. Hand hygiene with alcohol-based hand rub: how long is long enough? Infect Control Hosp Epidemiol 2017;38(5):547–52.
52. Pires D, Soule H, Bellissimo-Rodrigues F, et al. Antibacterial efficacy of handrubbing for 15 versus 30 seconds: EN 1500-based randomized experimental study with different loads of Staphylococcus aureus and Escherichia coli. Clin Microbiol Infect 2019;25(7):851–6.
53. Harnoss JC, Dancer SJ, Kaden CF, et al. Hand antisepsis without decreasing efficacy by shortening the rub-in time of alcohol-based handrubs to 15 seconds. J Hosp Infect 2020;104(4):419–24.
54. Kenters N, Eikelenboom-Boskamp A, Hines J, et al. Product dose considerations for real-world hand sanitiser efficacy. Am J Infect Control 2020;48(5):503–6.
55. Martinello RA, Arbogast JW, Guercia K, et al. Nursing preference for alcohol-based hand rub volume. Infect Control Hosp Epidemiol 2019;40(11):1248–52.

56. Best E, Parnell P, Couturier J, et al. Environmental contamination by bacteria in hospital washrooms according to hand-drying method: a multi-centre study. J Hosp Infect 2018;100(4):469–75.
57. Reynolds KA, Sexton JD, Norman A, et al. Comparison of electric hand dryers and paper towels for hand hygiene: a critical review of the literature. J Appl Microbiol 2021;130(1):25–39.
58. Baek E-H, Kim S-E, Kim D-H, et al. The difference in hand hygiene compliance rate between unit-based observers and trained observers for World Health Oganization checklist and optimal hand hygiene. Int J Infect Dis 2020;90:197–200.
59. Kovacs-Litman A, Muller MP, Powis JE, et al. Association between hospital outbreaks and hand hygiene: Insights from electronic monitoring. Clin Infect Dis 2020. [Epub ahead of print].
60. McLaws ML, Kwok YLA. Hand hygiene compliance rates: fact or fiction? Am J Infect Control 2018;46(8):876–80.
61. Lambe KA, Lydon S, Madden C, et al. Hand hygiene compliance in the ICU: a systematic review. Crit Care Med 2019;47(9):1251–7.
62. Mills JP, Zhu Z, Mantey J, et al. The devil is in the details: factors influencing hand hygiene adherence and contamination with antibiotic-resistant organisms among healthcare providers in nursing facilities. Infect Control Hosp Epidemiol 2019;40(12):1394–9.
63. Teesing GR, Erasmus V, Nieboer D, et al. Increased hand hygiene compliance in nursing homes after a multimodal intervention: a cluster randomized controlled trial (HANDSOME). Infect Control Hosp Epidemiol 2020;41(10):1169–77.
64. Chang NC, Reisinger HS, Jesson AR, et al. Feasibility of monitoring compliance to the My 5 Moments and Entry/Exit hand hygiene methods in US hospitals. Am J Infect Control 2016;44(8):938–40.
65. Cure L, Van Enk R. Effect of hand sanitizer location on hand hygiene compliance. Am J Infect Control 2015;43(9):917–21.
66. Scherer AM, Reisinger HS, Goto M, et al. Testing a novel audit and feedback method for hand hygiene compliance: a multicenter quality improvement study. Infect Control Hosp Epidemiol 2019;40(1):89–94.
67. Le CD, Lehman EB, Nguyen TH, et al. Hand hygiene compliance study at a large central hospital in Vietnam. Int J Environ Res Public Health 2019;16(4):607.
68. Kingston L, O'Connell NH, Dunne CP. Hand hygiene-related clinical trials reported since 2010: a systematic review. J Hosp Infect 2016;92(4):309–20.
69. Leis JA, Powis JE, McGeer A, 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.
70. Sickbert-Bennett EE, DiBiase LM, Willis TM, et al. Reduction of healthcare-associated infections by exceeding high compliance with hand hygiene practices. Emerg Infect Dis 2016;22(9):1628–30.
71. Edmisten C, Hall C, Kernizan L, et al. Implementing an electronic hand hygiene monitoring system: lessons learned from community hospitals. Am J Infect Control 2017;45(8):860–5.
72. Doll ME, Masroor N, Cooper K, et al. A comparison of the accuracy of two electronic hand hygiene monitoring systems. Infect Control Hosp Epidemiol 2019; 40(10):1194–7.
73. 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.

74. Pong S, Holliday P, Fernie G. Effect of electronic real-time prompting on hand hygiene behaviors in health care workers. Am J Infect Control 2018;46(7):768–74.
75. Pong S, Holliday P, Fernie G. Secondary measures of hand hygiene performance in health care available with continuous electronic monitoring of individuals. Am J Infect Control 2019;47(1):38–44.
76. Kerbaj J, Toure Y, Soto AA, et al. Smartphone text message service to foster hand hygiene compliance in health care workers. Am J Infect Control 2017;45(3):234–9.
77. Hagel S, Trodvjlr J, Kesselmeier M, et al. Quantifying the Hawthorne effect in hand hygiene compliance through comparing direct observation with automated hand hygiene monitoring. Infect Control Hosp Epidemiol 2015;36:957–62.
78. 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.
79. Jeanes A, Coen PG, Gould DJ, et al. Validity of hand hygiene compliance measurement by observation: a systematic review. Am J Infect Control 2019;47(3):313–22.
80. Reisinger HS, Yin J, Radonovich L, et al. Comprehensive survey of hand hygiene measurement and improvement practices in the Veterans Health Administration. Am J Infect Control 2013;41(11):989–93.
81. McCalla S, Reilly M, Thomas R, et al. An automated hand hygiene compliance system is associated with improved monitoring of hand hygiene. Am J Infect Control 2017;45(5):492–7.
82. Sunkesula VC, Meranda D, Kundrapu S, et al. Comparison of hand hygiene monitoring using the 5 moments for hand hygiene method versus a wash in-wash out method. Am J Infect Control 2015;43(1):16–9.
83. Boyce JM, Laughman JA, Ader MH, et al. 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.
84. Fisher DA, Seetoh T, Oh May-Lin H, et al. Automated measures of hand hygiene compliance among healthcare workers using ultrasound: validation and a randomized controlled trial. Infect Control Hosp Epidemiol 2013;34(9):919–28.
85. Nayyar D, Moore C, McCreight L, et al. Hand hygiene opportunities on Canadian acute-care inpatient units: a multicenter observational study. Infect Control Hosp Epidemiol 2018;39(11):1378–80.
86. Monsalve MN, Pemmaraju SV, Thomas GW, et al. Do peer effects improve hand hygiene adherence among healthcare workers? Infect Control Hosp Epidemiol 2014;35(10):1277–85.
87. Ellison RT III, Barysauskas CM, Rundensteiner EA, et al. A prospective controlled trial of an electronic hand hygiene reminder system. Open Forum Infect Dis 2015;2:ofv121.
88. Michael H, Einloth C, Fatica C, et al. Durable improvement in hand hygiene compliance following implementation of an automated observation system with visual feedback. Am J Infect Control 2017;45(3):311–3.
89. Yin J, Schacht Reisinger H, Vander Weg M, et al. Establishing evidence-based criteria for directly observed hand hygiene compliance monitoring programs: a prospective, multicenter cohort study. Infect Control Hosp Epidemiol 2014;35:1163–8.

90. World Health OWPS. A guide to the implementation of the WHO multimodal hand hygiene improvement strategy. World Health Organization; 2009. Available at: https://apps.who.int/iris/handle/10665/70030. Accessed January 14, 2021.
91. Dhar S, Tansek R, Toftey EA, et al. Observer bias in hand hygiene compliance reporting. Infect Control Hosp Epidemiol 2010;31(8):869–70.
92. Chen LF, Carriker C, Staheli R, et al. Observing and improving hand hygiene compliance: implementation and refinement of an electronic-assisted direct-observer hand hygiene audit program. Infect Control Hosp Epidemiol 2013; 34(2):207–10.
93. Brotfain E, Livshiz-Riven I, Gushansky A, et al. Monitoring the hand hygiene compliance of health care workers in a general intensive care unit: use of continuous closed circle television versus overt observation. Am J Infect Control 2017; 45(8):849–54.
94. Werzen A, Thom KA, Robinson GL, et al. Comparing brief, covert, directly observed hand hygiene compliance monitoring to standard methods: a multicenter cohort study. Am J Infect Control 2019;47(3):346–8.
95. Srigley JA, Furness CD, Baker GR, et al. Quantification of the Hawthorne effect in hand hygiene compliance monitoring using an electronic monitoring system: a retrospective cohort study. BMJ Qual Saf 2014;23:974–80.
96. Filho MA, Marra AR, Magnus TP, et al. Comparison of human and electronic observation for the measurement of compliance with hand hygiene. Am J Infect Control 2014;42(11):1188–92.
97. Vaisman A, Bannerman G, Matelski J, et al. Out of sight, out of mind: a prospective observational study to estimate the duration of the Hawthorne effect on hand hygiene events. BMJ Qual Saf 2020;29(11):932–8.
98. Scheithauer S, Bickenbach J, Heisel H, et al. Do WiFi-based hand hygiene dispenser systems increase hand hygiene compliance? Am J Infect Control 2018;46(10):1192–4.
99. Steed C, Kelly JW, Blackhurst D, et al. Hospital hand hygiene opportunities: where and when (HOW2)? The HOW2 Benchmark Study. Am J Infect Control 2011;39(1):19–26.
100. Azim S, Juergens C, Hines J, et al. Introducing automated hand hygiene surveillance to an Australian hospital: Mirroring the HOW2 Benchmark Study. Am J Infect Control 2016;44(7):772–6.
101. Kwok YL, Juergens CP, McLaws ML. Automated hand hygiene auditing with and without an intervention. Am J Infect Control 2016;44(12):1475–80.
102. Diller T, Kelly JW, Blackhurst D, et al. Estimation of hand hygiene opportunities on an adult medical ward using 24-hour camera surveillance: validation of the HOW2 Benchmark Study. Am J Infect Control 2014;42(6):602–7.
103. Conway LJ, Riley L, Saiman L, et al. 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(9):408–17.
104. Limper HM, Slawsky L, Garcia-Houchins S, et al. Assessment of an aggregate-level hand hygiene monitoring technology for measuring hand hygiene performance among healthcare personnel. Infect Control Hosp Epidemiol 2017; 38(3):348–52.
105. Moore LD, Robbins G, Quinn J, et al. The impact of COVID-19 pandemic on hand hygiene performance in hospitals. Am J Infect Control 2021;49(1):30–3.
106. Arbogast JW, Moore L, Clark T, et al. Who goes in and out of patient rooms? An observational study of room entries and exits in the acute care setting. Am J Infect Control 2019;47(5):585–7.

107. Brouqui P, Boudjema S, Soto Aladro A, et al. New approaches to prevent healthcare-associated infection. Clin Infect Dis 2017;65(suppl_1):S50–4.
108. Pineles LL, Morgan DJ, Limper HM, et al. Accuracy of a radiofrequency identification (RFID) badge system to monitor hand hygiene behavior during routine clinical activities. Am J Infect Control 2014;42(2):144–7.
109. Boyce JM, Cooper T, Yin J, et al. Challenges encountered and lessons learned during a trial of an electronic hand hygiene monitoring system. Am J Infect Control 2019;47(12):1443–8.
110. Boudjema S, Tarantini C, Peretti-Watel P, et al. Merging video coaching and an anthropologic approach to understand health care provider behavior toward hand hygiene protocols. Am J Infect Control 2017;45(5):487–91.
111. Armellino D, Hussain E, Schilling ME, et al. Using high-technology to enforce low-technology safety measures: the use of third-party remote video auditing and real-time feedback in healthcare. Clin Infect Dis 2012;54(1):1–7.
112. Armellino D, Trivedi M, Law I, et al. Replicating changes in hand hygiene in a surgical intensive care unit with remote video auditing and feedback. Am J Infect Control 2013;41(10):925–7.
113. Yeung S, Downing NL, Fei-Fei L, et al. Bedside computer vision - moving artificial intelligence from driver assistance to patient safety. N Engl J Med 2018;378(14):1271–3.
114. Larson EL, Murray MT, Cohen B, et al. Behavioral interventions to reduce infections in pediatric long-term care facilities: the keep it clean for kids trial. Behav Med 2018;44(2):141–50.
115. Limper HM, Garcia-Houchins S, Slawsky L, et al. A validation protocol: assessing the accuracy of hand hygiene monitoring technology. Infect Control Hosp Epidemiol 2016;37(8):1002–4.
116. McCalla S, Reilly M, Thomas R, et al. An automated hand hygiene compliance system is associated with decreased rates of healthcare-associated infections. Am J Infect Control 2018;46(12):1381–6.
117. Tarantini C, Brouqui P, Wilson R, et al. Healthcare workers' attitudes towards hand-hygiene monitoring technology. J Hosp Infect 2019;102(4):413–8.
118. Meng M, Sorber M, Herzog A, et al. Technological innovations in infection control: a rapid review of the acceptance of behavior monitoring systems and their contribution to the improvement of hand hygiene. Am J Infect Control 2019;47(4):439–47.
119. 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, NJ: Wiley-Blackwell; 2017. p. 299–316.