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Hand Hygiene: State-of-the-Art Review With Emphasis on New Technologies and Mechanisms of Surveillance

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Abstract Hand hygiene (HH) is an important measure in infection prevention to decrease transmission of microbial pathogens; however, HH compliance by health-care workers (HCWs) remains suboptimal. One of the principal recommendations of current guidelines is that waterless, alcohol-based hand rubs are the preferred method for HH in most situations, due to the superior efficacy of these agents in rapidly reducing bacterial counts on hands and their ease of use. Improving HH compliance is a good quality indicator for hospital patient safety programs. Observers can follow HCWs to perform direct HH observations; however, HCWs may be prompted to clean their hands when observers are nearby, which does not represent real-world conditions. Moreover, having observers walk into patient rooms violates patient privacy and is time consuming. HH strategies using indirect metrics for surveillance (e.g., measuring the volume of HH products consumed) and the use of new technologies (e.g., electronic dispenser counters, radiofrequency, alcohol sensors, and video recording) will also be discussed.

Keywords Hand hygiene · Compliance · Electronic handwash counters · Alcohol-based hand rubs

Introduction

The goal of hand hygiene (HH) is to limit the transmission of pathogens between health-care workers (HCWs) and patients [1, 2]. There are several Centers for Disease Control and Prevention guidelines for HH [1, 4–6]. The first one was published in 1994 and was updated in 2002 [1]. HH is considered a category IA intervention (meaning that it is strongly recommended for implementation in all hospitals), but the evidence to support it is relatively weak (it is only considered category II—derived from historical cohort studies) [1].

Physicians are all familiar with the randomized, controlled study [3••], which is considered the optimal study design; however, many studies in infection prevention do not utilize this methodology. The majority of HH intervention studies are quasi-experimental, primarily uncontrolled before-and-after studies [3••] or controlled before-and-after studies with a nonequivalent control group [7]. These designs do not have a standard nomenclature and are hampered by confounding and regression to the mean [8]. Quasi-experimental study designs are frequently used when it is not logistically feasible to conduct a controlled trial [9]. Thus, there is a need for improved study design for HH intervention studies.

Although there are no standardized methods for measuring HH compliance, direct observation is noted by the World Health Organization (WHO) as the gold standard method for assessing HH adherence rates [10].

HH is a major infection control prevention strategy, but in many medical centers where alcohol gel has been implemented, HH compliance rates are only approximately 50 % [11–13]. The most common reasons given by HCWs for noncompliance include insufficient time, work overload, excess patient loads, lack of knowledge of the recommendations, skepticism about HH as a prevention method, inconvenient locations for sinks and soap dispensers, and lack of incentive for compliance with HH [1].

Ignaz Semmelweis was the first to understand the importance of HH [14], and he made HH mandatory for HCWs, principally doctors. At that time, there was a significant difference in the maternal mortality rate between the first and second clinics of his hospital. This difference was

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reduced by Semmelweis's HH intervention. However, 150 years later, very low HH compliance rates persist [11–13, 15]. As compared with other infection control process measures (e.g., elevating the head of the bed to prevent ventilator-associated pneumonia and avoiding femoral intravascular catheters to prevent central-line-associated bloodstream infection), compliance with HH remains poor [16].

It is important to point out that HH opportunities during routine patient care are numerous, and for each opportunity, an estimated 60–80 s are required to perform HH with soap and water.

Alcohol-Based Hand Rub

HH compliance can be affected by both the accessibility of and formulation of these HH products (liquids, gels, and foams) [1, 17]. Alcohol-based HH requires less time than washing hands with soap (plain or medicated) and water and is as effective [1, 17]. A principal recommendation in current guidelines is for the use of waterless, alcohol-based hand rubs (ABHRs; liquids, gels, or foams) as the preferred method for HH, due to ease of application and superior bactericidal efficacy.

A prospective observational study by Bischoff et al. demonstrated that simply implementing alcohol gel was an effective strategy for improving HH compliance [12]. Pittet et al. observed improvement during a 3-year observational period, and although enhanced compliance with HH using an alcohol-based product was evident as early as the first 6 months of observation, rates stabilized in the last 18-month period [11].

Rupp et al. performed a prospective controlled, crossover trial of alcohol-based hand gel in two critical care units, showing that the introduction of alcohol-based gel resulted in a significant and sustained improvement in the rate of HH adherence. However, they did not detect changes in the incidence of health-care-associated infections [13]. The use of alcohol gel for HH compliance appears to be increasing over time [18•].

Although the newly developed "Five Moments for Hand Hygiene" from the WHO can add value to any HH improvement strategy [17, 19••], in many medical centers where alcohol gel has been implemented, HH compliance rates are only approximately 50 % [12, 13, 20, 21].

Interventions for Improving Hand Hygiene Compliance

A systematic review from the Cochrane Collaboration on interventions to improve HH compliance found only four studies that met criteria for the review [3••]. Two studies evaluated simple education initiatives, one using a randomized clinical trial design and the other a controlled before-and-after design. Both measured HH compliance by direct observation. The other two studies were both interrupted times series studies. One study presented three separate interventions within the same paper: simple substitutions of product and two multifaceted campaigns, one of which included involving practitioners in making decisions about choice of HH products and the components of the HH program. The other study also presented two separate multifaceted campaigns, one of which involved application of social marketing theory. In these two studies, follow-up data collection continued beyond 12 months, and a proxy measure of HH compliance (product use) was recorded. Microbiological data were recorded in one study. HH compliance increased for one of the studies, where it was measured by direct observation, but the results from the other study were not conclusive. Product use increased in the two studies in which it was reported, with inconsistent results reported for one initiative. Methicillin-resistant *Staphylococcus aureus* (MRSA) incidence decreased in the one study reporting microbiological data [3••].

Methods for Evaluating Hand Hygiene Compliance

Direct observation is considered the gold standard method for evaluating HH compliance [1, 10, 22]. Recent publications by Elaine Larson [10, 23•] and John Boyce [24••] discussed measuring the volume of HH products consumed in liters per 1,000 patient days and using electronic handwash counters as options for evaluating HH compliance. HH episodes can be recorded by electronic handwash counters for alcohol gel [24••, 25, 26]. The alcohol gel dispenser (NXT 1 liter model) records only one episode in any 2-s period, even if more than one aliquot of alcohol is dispensed. The total volume of product used can then be expressed in liters per 1,000 patient days [25–27].

Although observation is considered the gold standard method, one study found that the episodes observed represented only 1.3 % of the estimated number of HH opportunities [18•]. The same study found a strong correlation between the number of dispensing episodes per patient days and ABHR consumption per patient-days, but there was no correlation between the rate of HH adherence and alcohol gel consumption per patient days [18•]. However, studies employing direct observation are likely biased by the "Hawthorne effect" [28].

The electronic handwash counter on dispensers of ABHRs is an important tool for obtaining data about HH, offering a different opportunity to capture HH adherence in the hospital setting [24••, 25, 26], principally in the ICU [18•]. The electronic handwash counter should supplement, and not yet supplant, direct observation, since it is not able to evaluate the HH quality that HCWs perform during ABHR use [18•, 24••]. It has been also demonstrated that directly observed rates of adherence may not be accurate because they did not correlate with volumes of product used, assuming that the number of opportunities for HH is relatively stable. In one such study, ICU nurses surreptitiously recorded opportunities for HH and compliance on a hand-held personal digital assistant (iPod, Apple) using an application (iScrub) [29, 30].

Recently, the number of nurse visits to patient rooms was measured by a nurse call system, which was installed in two step-down units [31]. The additional metric of compliance with the use of alcohol-based hand rubs by the nursing staff allowed calculation of the number of alcohol rub aliquots dispensed/number of nurse visits to patient rooms [31].

Generally, HH studies using observers have 60-min HH observation periods [10, 18•, 28]; however, electronic counters record 24 h per day. More recently, a 12-week study [18•] measured HH with direct observation and electronic counting devices on dispensers and by measuring the volume of HH products used. Direct observation yielded a compliance rate of 62 %. Another study [32•] assessed HH compliance through a 30-week quasi-experimental study using automated count technology and direct observation by a secret shopper with a feedback intervention. Electronic HH dispenser counts increased significantly in the postintervention period, relative to the preintervention period, with an average count/patient-day increase of 22.7 in the neuro ICU and 7.3 in the cardiac care ICU (both ps $<$.001). However, direct observation of compliance did not change significantly (percent compliance increased by 2.9 % in the neuro ICU and decreased by 6.7 % in the cardiac care ICU; p=.47 and p=.07, respectively). The investigators concluded that passive, electronic monitoring of HH dispenser count does not correlate with direct human observation of HH and that this electronic device was more responsive than observation to a feedback intervention [32•].

Electronic Hand Hygiene Compliance Monitoring Systems

Electronic HH systems are designed to ensure that HCWs perform HH prior to patient care and issue an automated notice to do so. One study placed electronic monitoring devices on AHBR dispensers, which also had motion detectors, outside 12 patient room entrances on one unit. The investigators defined an HH opportunity as an entry to or an exit from one of the 12 rooms [33]. If HH was not performed on entry or exit, the device produced a flashing light and a series of three simultaneous beeps, along with a prerecorded voice prompt that said, “Please wash your hands.” The system recorded each HH opportunity and each time hand rub was dispensed to an HCW in conjunction with the opportunity. The authors concluded that the electronic devices not only effectively monitored HH adherence, but also facilitated improvement in compliance from a baseline of about 36 % to about 70 % after the electronic monitoring devices were in use.

Another study [34] conducted a two-phase intervention study that included 4 weeks of direct observation of HH compliance (phase 1), followed by a 2-week evaluation of an HH alerting system in which nurses wore alcohol-sensing badges. Room sensors detected room entry and exit by HCWs wearing badges. The badge alerted HCWs to the need to perform HH, using a light and an audible reminder embedded in the badge. The light on the badge turned green if the sensor embedded in the badge detected alcohol on the hands of the HCW within a set number of seconds after entering the room but turned red if alcohol was not detected by the badge. All of the data from the badges were transmitted via wireless telemetry to a software application where individual HCW compliance rates could be monitored. Using this system, they demonstrated significant improvement in HH compliance.

Another promising technology employs an HH monitoring system that uses a wall-mounted sensor to create an infrared zone around a patient’s bed, which can detect the presence of badge-wearing HCWs near the bed. The only inconvenience is that HCWs need to pass their hands under another sensor that detects alcohol handrub on their hands. When this occurs, a light on the badge turns green, and the HCW is given credit for being compliant. If this is not done, the badge vibrates to remind the HCWs to clean their hands. As with the previous technology, the HH compliance using this system was very high (94 %) [35].

RFID (Radio Frequency Identification)

It has been suggested that RFID technology may be useful in monitoring HH compliance. It is important to note that this technology is expensive and generates high maintenance costs, although this technology is attractive from the standpoint of cost when there are many tags for a few receivers. Another important consideration is that this technology is not yet widespread. The great attractiveness of RFID technology is that the badges do not require batteries. The use of other technologies (such as WiFi or Zigbee, which are wireless technologies) will require the use of buttons or buttons with batteries. However, the maintenance/replacement of the battery of these buttons may prove easier to maintain and may be cheaper than the maintenance and hardware for RFID.

Other Technologies for Identification (Wireless Technologies)

Other studies [33, 34] have evaluated new options for identification technologies [35]. Among those that are more widespread, including for use in medical equipment, there are WiFi (wireless system based on IEEE 802.11 standards) and Zigbee (wireless communication protocols based on IEEE 802.15.3 standards [36]. Both are receivers of low cost, are easy to maintain, and can be portable. Many medical device manufacturers are already using this technology to exchange information [24••]. This technology, in addition to identification, allows the exchange of information in both directions at high speed (even in remote monitoring systems). In addition, mobile devices, such as mobile phones, smartphones, or tablets, have communication via WiFi, raising the possibility of new applications (e.g., the use of mobile phones for HCW identification or communication). The major inconvenience of this technology would be the need to use batteries in the badge that will be attached to the clothing of the HCW [24••].

A disadvantage of Zigbee is that accuracy may require multiple beacons in an area or combination with another technology; some systems may credit two HCWs with an HH event if the HCWs are very close in proximity [24••].

A future concept is to develop a wireless ID device to detect and link HCW HH with a given alcohol hand rub dispenser in a patient room. This technology would be equipped with automated warning lights and warning sensors close to the patient bed. These technologies, integrated with a database, would allow for automated reports of HCWs entering rooms and HH adherence and a log of patient care episodes per each HCW. This would allow the use of a feedback loop in real time to improve HH compliance. Feedback loops are profoundly effective tools for changing human behavior, which are based on a simple premise: Give people information about their actions in near-real time; then show them how to change those actions into better behaviors [37].

The use of these new technologies in medical equipments or within beds is not yet widespread. One of the reasons is the cost and the ease of installation of the necessary infrastructure. Even those institutions that have the ability to implement HH electronic systems need to consider an interface with engineering in order to examine whether there may be interference with existing equipment or whether an existing wireless network may be overloaded [24••]. Also, further information is needed in order to know the real proportion of HH opportunities captured by this HH system to avoid a misunderstanding about HH compliance rates (e.g., when HCWs entering the room do not touch the patient or the environment) [24••].

Video Surveillance

A recent study placed cameras with views of every sink and hand sanitizer dispenser to record HH of HCWs. Sensors in doorways identified when an individual(s) entered/exited. When video auditors observed an HCW performing HH upon entering/exiting, they assigned a pass; if not, a fail was assigned. HH was measured during a 4-month baseline period of remote video auditing without feedback (with an HH compliance of less than 10 %), and in the 4-month postfeedback period, it was 81.6 %. The increase was maintained through 75 weeks at 87.9 %. Performance feedback was continuously displayed on electronic boards mounted within the hallways, and summary reports were delivered to supervisors by electronic mail. The remote video monitoring of HH with real-time feedback to HCWs was responsible for a significant increase in HH compliance [38].

Changing Behavior

In every community or organization, there are certain individuals or groups whose uncommon practices enable them to find better solutions to problems than their neighbors or colleagues, despite having access to the same resources. These individuals are known as positive deviants [39].

Positive deviance (PD), pioneered by Jerry and Monique Sternin of the Positive Deviance Initiative (PDI), has been used worldwide to combat such intractable problems as childhood, malnutrition, sex trafficking of girls, and poor infant health [40]. PD has been used to control MRSA in the health-care setting [41].

The PD approach is totally different form the traditional approach for stimulating HH improvement. In PD, the HCWs decide how the work should be done, and they promote discovery among their peers. The leadership and managers support frontline workers in implementing new ideas into their routine [42]. The positive deviants discuss problems that they have noticed (e.g., Dr. X did not wash his hands before a patient examination; Dr. Y did not perform HH even after examining a patient in contact precautions). Participants discuss ways to stimulate a discussion with noncompliant individuals in a positive manner. No embarrassment is permitted.

Fig. 1 An example of positive deviance: placement of alcohol gel dispensers on mobile X-ray machines

Solutions suggested by the positive deviants included changing the position of the alcohol rub dispensers to allow easier access and use, putting alcohol gel dispensers on mobile X-ray machines (Fig. 1), and changes to the procedure for monitoring the consumption of alcohol handrub product, which was initially performed by one single staff member each 48 h and gradually evolved to become the responsibility of every professional involved with patient care at the end of their shifts [43••].

In our experience, the nurse managers facilitated the discussions among frontline workers and gave the positive deviants opportunities to express their feelings about HH and to discuss what needed to be changed, what needed to be improved, what was wrong, and what was right. One of the strategies from the PD project for improving HH compliance was to show the final number of alcohol gel aliquots dispensed per unit and to compare data and HCW impressions [44].

Participants in positive deviance meetings include, in addition to the nursing staff, physical therapists, pharmacists, dietitians, physicians, and cleaning and food service staff. During one of these meetings, the idea of using an indirect metric to assess staff adherence to HH practices emerged—that is, the ratio between the number of alcohol rub aliquots dispensed (registered on the electronic counters) and the number of nurse visits to patients' rooms (obtained from the nurse call system reports). The proposal was brought up during a discussion about the value of the month-by-month comparison of the alcohol hand rub use, where there was concern regarding variation in product use due to changes in occupancy rates and workload in the hospital unit [31].

The WHO has made a concerted effort to improve HH compliance around the world, recruiting many institutions to participate in their HH program [17, 19••]. The WHO's "My Five Moments for Hand Hygiene" [19••] has been incorporated into our PD program to improve compliance.

Positive deviants are multipliers, and this contributes to the success of the PD program for HH [20, 45].

Translational Science

Translational science entails the development of strategies and tools that allow discoveries that will benefit the patient and society. There is a considerable gap between initial experimental results and their transformation into new technologies in health [46], and translational science aims to fill this gap. The "My Five Moments for Hand Hygiene" is an example of translational science.

Displaying posters with gain-framed messages, messages promoting HH emphasizing the positive consequences of adherence, is theoretically effective in motivating HCWs′ HH behavior [47] and may promote HH in daily practice. An interrupted time series analysis conducted in a neonatal intensive care unit (NICU) tested the impact of gain-framed messages on the frequency of hand disinfection events and compliance in the NICU, using electronic devices on hand alcohol dispensers. They noticed a negative trend in HH events per patient day before the intervention (decreased by 2.3 [standard error, 0.5] per week), which changed to a significant positive trend (increased of 1.5 [0.5] per week) after the intervention ($p<.01$) [48].

Conclusions

Although HH is considered a simple intervention, it likely represents the most powerful infection prevention method available. Using observers for evaluating HH compliance, although considered the gold standard, is neither a simple nor a reliable task. Behavioral changes to improve HH, using positive deviance strategies, may result in HH improvement. New technologies for the measurement of HH should improve the accuracy of HH surveillance and improve compliance. Widespread use of new technologies for HH is hampered, at present, by issues of cost and availability.

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