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Major Article

Secondary measures of hand hygiene performance in health care available with continuous electronic monitoring of individuals

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Background: Hand hygiene (HH) compliance in health care is usually measured against versions of the World Health Organization's "Your 5 Moments" guidelines using direct observation. Such techniques result in small samples that are influenced by the presence of an observer. This study demonstrates that continuous electronic monitoring of individuals can overcome these limitations.

Methods: An electronic real-time prompting system collected HH data on a musculoskeletal rehabilitation unit for 12 weeks between October 2016 and October 2017. Aggregate and professional group scores and the distributions of individuals' performance within groups were analyzed. Soiled utility room exits were monitored and compared with performance at patient rooms. Duration of patient room visits and the number of consecutive missed opportunities were calculated.

Results: Overall, 76,130 patient room and 1,448 soiled utility room HH opportunities were recorded from 98 health care professionals. Aggregate unit performance for patient and soiled utility rooms were both 67%, although individual compliance varied greatly. The number of hand wash events that occurred while inside patient rooms increased with longer visits, whereas HH performance at patient room exit decreased. Eighty-three percent of missed HH opportunities occurred as part of a series of missed events, not in isolation.

Conclusions: Continuous collection of HH data that includes temporal, spatial, and personnel details provides information on actual HH practices, whereas direct observation or dispenser counts show only aggregate trends.

BACKGROUND

Direct observation of the World Health Organization's (WHO) "Your 5 Moments" guidelines is the primary measure of hand hygiene (HH) compliance in health care.[1-3] This aggregate measure, with a focus on direct patient interactions, provides only a partial understanding of the HH behaviors that contribute to the potential spread of health care–acquired infections.[4,5] Because of small sample sizes and inherent biases, manual audits contribute little to our knowledge of actual HH practices.[6-8] With the advent of electronic monitoring systems (EMSs) and the ability to collect information continuously about individual participants' activity comes substantially more information.[9-12] Although many EMSs focus on developing different methods of collecting and reporting compliance against the existing primary measure, we suggest that this additional data can be used to more fully understand health care professional (HCP) HH activity by developing additional or secondary measures of HH performance.

The aims of this study are to demonstrate the value of high-resolution, individual participant data for understanding HH behaviors by reporting and comparing the performance of individual participants, HCP groups, and unit level aggregate results. We also investigate 3

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measures of HH performance in addition to those outlined by the WHO: (1) time as it relates to calculating HH compliance and the amount of time spent in patient rooms, (2) the number of consecutive missed HH opportunities by individuals, and (3) HH performance in additional monitored areas. These secondary measures augment existing understanding of HH behaviors by extending the boundaries of measurement beyond single moments and places to continuous accounting of time and space by individuals, not only groups.

METHODS

Data collection for this cross-sectional study was completed using an EMS developed by the research team at Toronto Rehabilitation Institute, Canada. Electronic badges worn by staff collect information about hand washing activity from electronic controllers installed in all soap and alcohol-based hand rub (ABHR) dispensers and on the ceiling, inside and outside all monitored zones including all patient rooms.[13,14] The dispenser controllers transmit unique identification codes to badges indicating that a hand wash event has occurred. Zone controllers on the ceiling are used to monitor staff movement into and out of monitored zones. These zones operate at the room level, with transitions occurring at the doorway or threshold of the monitored room. This recorded information is used by the badges to produce real-time prompts to wash within a second of crossing the threshold if staff have not washed their hands within the defined time constant of 60 seconds before crossing.[15] Badges prompt the wearer to wash by producing a discrete vibration detectable only by the wearer. This vibration lasts for 20 seconds or until an instrumented soap or ABHR dispenser is used, whichever comes first. The badges collect a rich audit record of temporal and spatial information for each participant including time and location of hand washing, dispenser type, zone changes, and HCP group allocation.[16]

The EMS was installed on a musculoskeletal rehabilitation nursing unit. Monitored zones included all patient rooms: 10 single-bed and 10 double-bed. In consultation with unit managers and infection prevention and control practitioners, the soiled utility room was identified as a concern because of the concentration of contaminated materials and was also instrumented as a monitored zone.[17] All wall-mounted dispensers were instrumented: 47 soap and 64 ABHR. There is an ABHR dispenser immediately outside every patient room. Inside, there is an ABHR dispenser beside every bed. All patient rooms have a centrally located sink with a soap dispenser. Every patient room has a single bathroom with a soap dispenser located inside. Therefore single-patient rooms have 1 ABHR and 2 soap dispensers inside and 1 ABHR dispenser immediately outside the room beside the doorway. Multibed patient rooms have 1 additional ABHR dispenser per additional bed located on the wall beside the patient's bed.

Data were collected during three 4-week sessions between October 3, 2016, and October 29, 2017, as part of a quality improvement initiative. The University Health Network Ethics Board waived the requirement for consent based on the quality improvement focus of the project. Generally, staff participation in such projects is required within the institution. For this study, however, there were no repercussions for nonparticipation. All staff members working on the unit were asked to participate for the entire study, issued their own electronic badges, and assigned to 1 of 5 HCP groups: administration, allied health, doctor, housekeeping, or nurse.

STATISTICAL ANALYSIS

HH performance for patient rooms was calculated by dividing the number of times hand washing occurred within 1 minute before or 20 seconds after entering or exiting a patient room divided by the total number of patient room entries and exits (opportunities).[18] Soiled utility room performance was calculated for exit opportunities only. It was determined that because staff often carry contaminated objects into the soiled utility room and there are no patients in that area, it would not reduce the risk of hand or patient cross-contamination to require washing at entry.[18] For all measures, the binomial dependent variable of HH performance, missed or clean, was analyzed with logistic regression.

The series length of missed HH opportunities was determined by counting the number of consecutive patient room HH opportunity misses by an individual. For the sake of comparison, single missed opportunities are reported as series of length 1. Use of any hand wash dispenser (ABHR or soap) at any time or the end of a participant's shift terminated the series.

Analyses of patient room visit duration and series length frequency of missed HH opportunities were calculated by HCP group with Kruskal-Wallis tests. Statistical analyses were completed using R version 3.3.2 (R Foundation for Statistical Analysis, Vienna, Austria).

RESULTS

Patient rooms were visited 38,065 times (76,130 entry and exit opportunities) by 98 unique participants (housekeeping [n = 6], administration [n = 7], doctor [n = 8], allied health [n = 18], nurse [n = 59]). Aggregate HH performance for the entire study was 67%. Figure 1 indicates when hand washing events occurred relative to the time of patient room entry and exit (0 seconds), along with the percent of opportunities when hand washing occurred before entry/exit, after being prompted, or not at all.

The amount of time spent in patient rooms significantly predicted HH performance at both patient room entry, $P < .0001$, (B [SE] = −.0001 [<.0001]), and patient room exit, $P < .0001$, (B [SE] = −.0002 [<.0001]) (Fig 2). HCP group assignment was a significant predictor of how long staff stayed inside patient rooms per visit: $H(527.19) = 4$, $P < .0001$. The majority of all patient room visits were less than 1 minute in duration. The median duration of patient room visits by HCP was 27 seconds for housekeeping, 41 seconds for administration, 51 seconds for allied health, 51 seconds for nurses, and 104 seconds for doctors.

HCP group was a significant predictor of HH performance when visiting patient rooms, $\chi^2(4) = 2750.72$, $P < .0001$. The aggregate HCP group performance of doctors, allied health professionals, and administrators was the same at 87%. Nursing and housekeeping group performance was 67% and 57%. The distribution shapes of HH performance by individuals, within HCP groups, were all negatively skewed: there were more high performers than low in every group. The distribution for those in the nursing group was the widest, with the lowest individual user performance score of 10%. The distributions within the other HCP groups were bimodal, showing higher scores for the majority and lower performance scores for a smaller number of individuals in each group (Fig 3).

The frequency of consecutive missed opportunity series lengths is shown in Figure 4. The majority of missed HH opportunities (83%) was part of a series of missed opportunities, whereas only 17% occurred as single isolated events. HCP group was a significant predictor of the series length of missed HH opportunities: $H(170.57) = 4$, $P = .0001$. The median length of all missed series was 4. By HCP group, administration had the shortest median missed series at 1, whereas housekeeping had the longest at 11. The longest single series of missed opportunities was 146 by housekeeping staff.

The soiled utility room was visited 1,448 times by staff from only 3 of the 5 HCP groups for an aggregate HH performance compliance of 67%. For the given dataset, HCP group was a strong predictor of HH performance when exiting the soiled utility room: $\chi^2(2) = 35.70$, $P <$

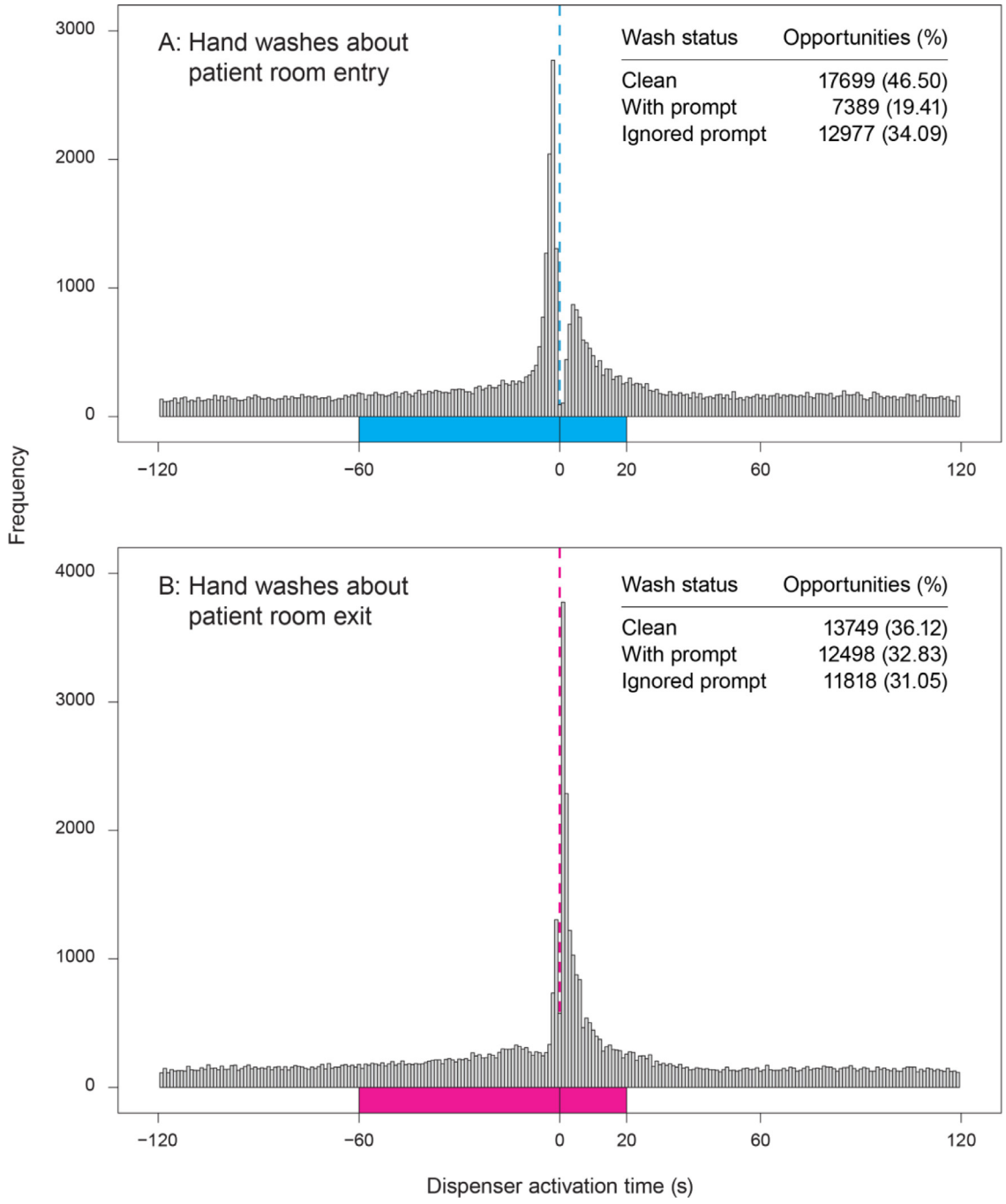

Fig 1. Number of hand wash events before and after patient room entry (A) and exit (B). Color bars below histograms show time constants used to determine performance: hand washes occurring within 60 seconds before (Clean) and up to 20 seconds after (With prompt) patient room entry or exit count as compliant opportunities. Ignored prompt indicates number of times staff were prompted to wash but did not comply within 20 seconds. Dashed vertical lines at 0 seconds indicate when prompt to wash was initiated.

.0001. HCP group results for HH performance at the soiled utility room are presented in Table 1.

DISCUSSION

Electronic HH monitoring systems capable of tracking individual HCP HH actions have benefits over traditional observational HH audits or electronic systems that only report aggregate performance. Specifically, we suggest that aggregate-based audits do not report the length of time spent in patient rooms, track consecutive missed HH opportunities, combine potentially important information such as length of time spent in patient rooms with HH performance, or focus on potentially hazardous areas outside of the patient environment such as the soiled utility room.

Personnel reporting resolution

Tracking and reporting aggregate unit level HH performance among health care staff may show overall trends but does not identify staff activities that might put patients at greater risk of infection. To more effectively achieve the goal of reducing cross-contamination of patients, one needs to know how individuals are performing. Although HCP group is a predictor of performance, the distribution of performance by individuals differed

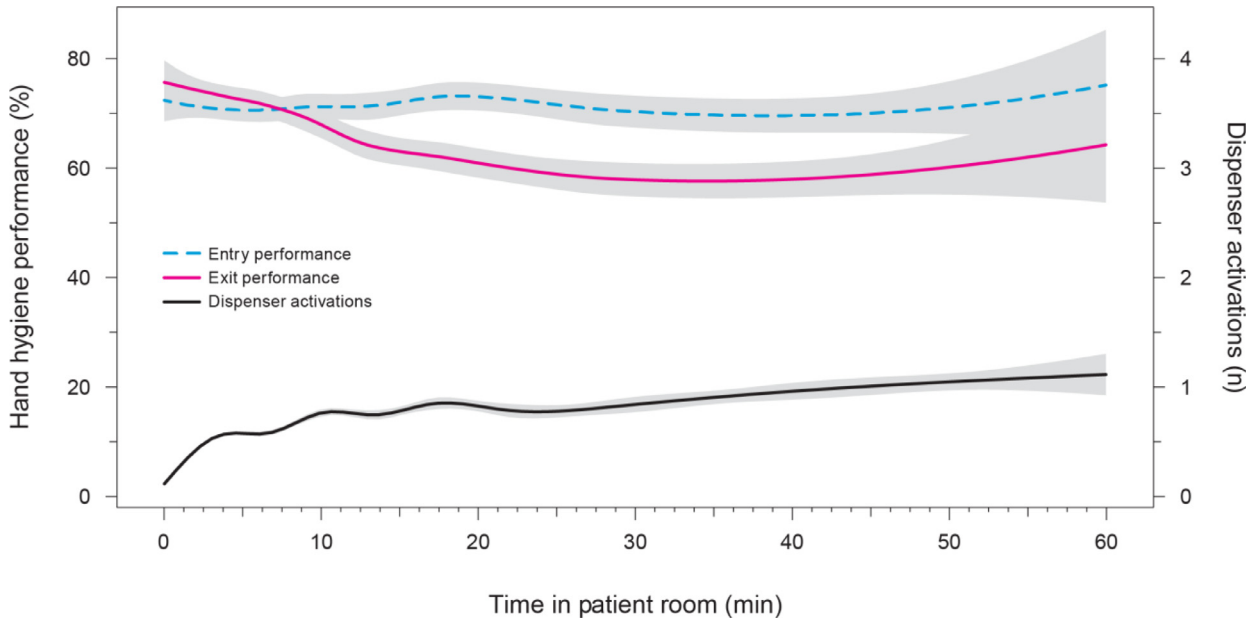

Fig 2. Change in aggregate HH performance at patient room entry and exit and the number of times hand washing occurred while inside patient rooms over time up to 60 minutes. HH performance scale is the left y-axis. The number of dispenser activations that occurred while inside patient rooms is the right y-axis.

within HCP groups. Figure 3 presents unit level aggregate, HCP group level aggregate, and individual performance by HCP group demonstrating how aggregate reporting can mask individual staff performance. The nursing group had a long distribution tail in contrast to the other groups, which had larger concentrations of high-performing individuals and smaller concentrations of lower performers.

Analyses of the distributions allow us to compare between and within groups. We are able to identify poor and excellent performers in each discipline. Ultimately, infections are spread by individuals, not groups of people. Such information can be used to understand the actual levels of compliance, versus small unrepresentative samples obtained via other methods such as self-reporting or direct observation.[19]

Time constants for calculating HH compliance

All sophisticated methods of calculating HH performance other than monitoring product use or hand wash counts rely on time-based evaluations to calculate compliance. Even auditors involved in direct observation, although not explicitly defined beyond the terms

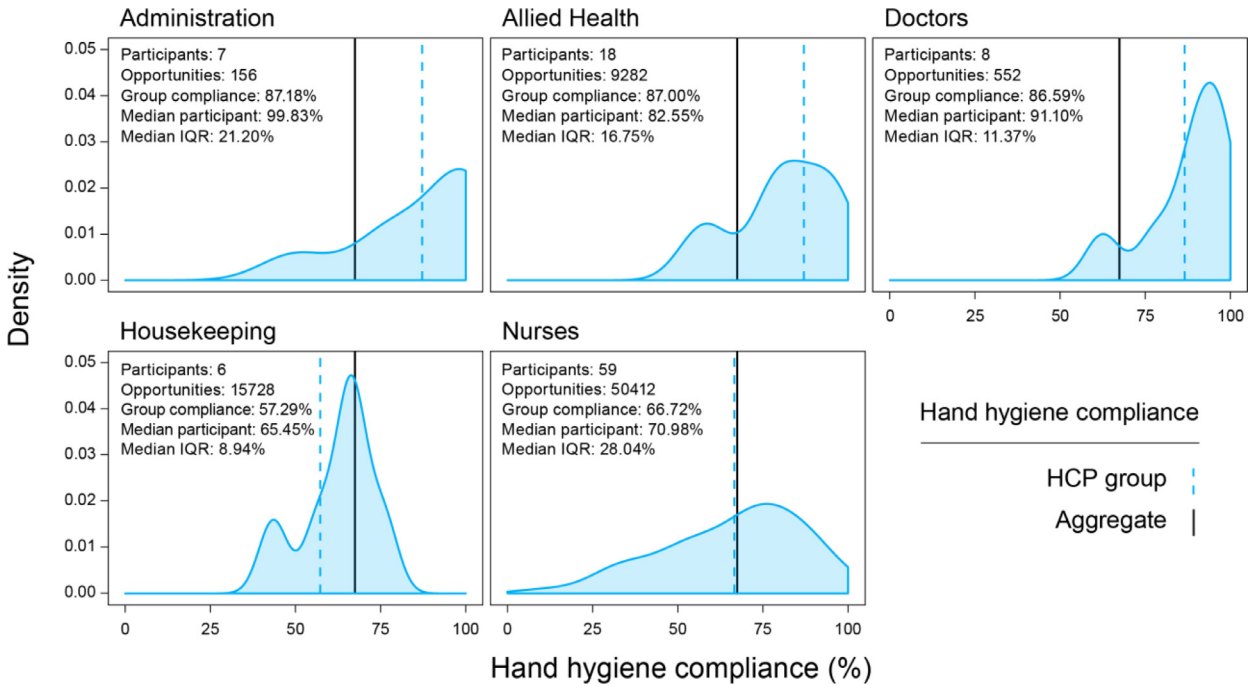

Fig 3. Individual, HCP group, and unit level HH performance results. The aggregate HH performance of all opportunities on the unit is the solid black line (67.43%); the aggregates of HCP group HH performance are dashed lines. Density plots or curves are used to visualize the distribution of individual participant HH performance within HCP groups and reveal concentrations of performance results. *HCP*, health care professional; *IQR*, interquartile range.

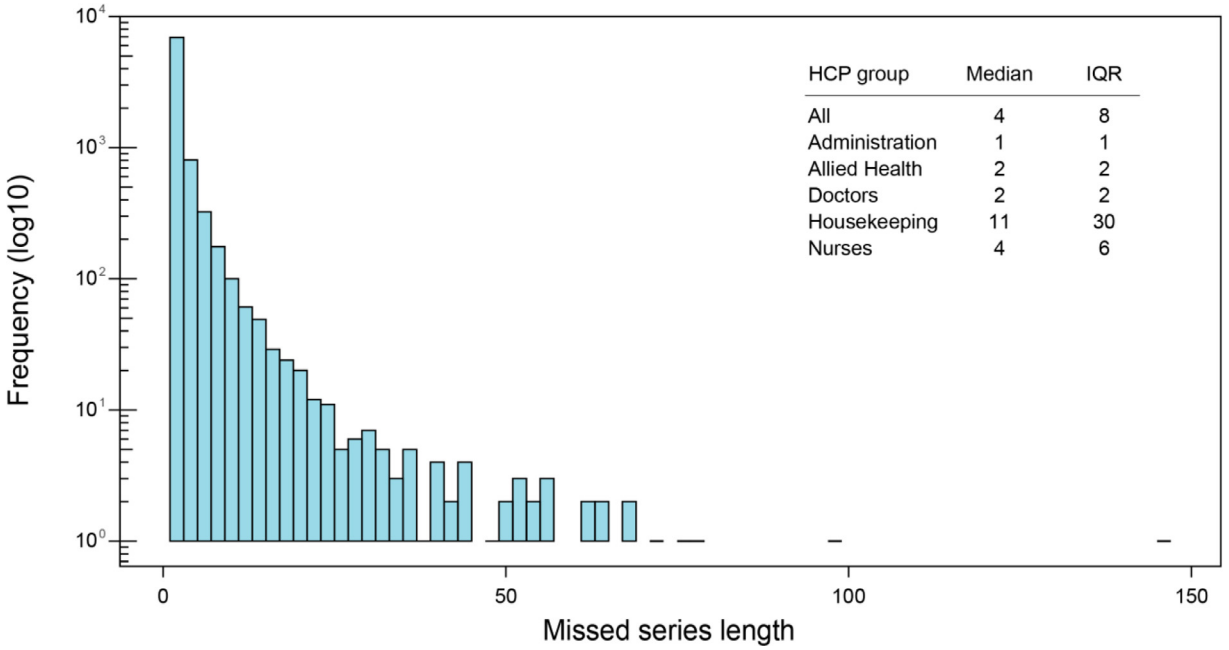

Fig 4. Histogram of all consecutive missed opportunity series lengths for all users. Median and interquartile range (IQR) of missed series lengths are presented by health care professional (HCP) group.

"before" and "after," subjectively use time to determine compliance. It is therefore important to understand what time constants are being used, how they were chosen, and how they impact performance results. By tracking when and where hand washing occurs, the system used in this study is able to monitor and credit both proactive washing that takes place before an opportunity and reactive washing that takes place immediately after a missed opportunity while being prompted.

Our system allows users to wash up to 1 minute before entry and exit and up to 20 seconds after entry and exit. Figure 1 demonstrates that changes to the system's time constants would impact performance results and that comparisons to other systems using differing constants would be difficult. When selecting the amount of time allowed for compliant washing, it would be easy to argue that shorter is better: providing less time for potential hand recontamination results in less chance of spreading infection. This decision, however, needs to be balanced with practical application and acceptance of the system as a whole by participating staff.[20] A time constant before room entry should allow completion of the hand wash activity, including application of ABHR to the skin and an amount of time in which the ABHR is still effective before the opportunity. The amount of time permitted after room entry, in this case, allows staff time to respond to prompts to wash: locating and moving to a dispenser and time to use it. Electronic application of time constants result in objective and consistent application of rules.

Table 1
Soiled utility room HH performance by HCP group.

HCP group	Performance	Opportunities, n	*B*(*SE*)	Odds ratio (95% confidence interval)
Allied health	91.14%	79	—	1
Facilities	59.57%	371	−1.94* (0.41)	0.14 (0.06-0.30)
Nurses	68.44%	998	−1.56* (0.40)	0.21 (0.09-0.43)

NOTE. Hand hygiene (HH) performance based on exit only. $R^2 = .02$ (Hosmer-Lemeshow), .024 (Cox-Snell), .034 (Nagelkerke).
HCP, health care professional.
*$P < .001$.

Time spent in patient rooms

Beyond using time to calculate performance, it can also be used to understand HH behaviors through expanded reporting and analysis. In general, as the amount of time spent in a room increases, so does the likelihood of contacting a patient or the environment. Length and type of patient care affect ungloved HCP hands with a linear increase of bacterial contamination over time.[21] Figure 2 shows that aggregate HH performance at patient room exit varies over time more than that at room entry. At shorter room visits, the exit performance is relatively high, but at around the 8-minute mark it crosses and stays below entry performance. Shortly after the 22-minute mark, changes in HH performance for patient room entry and exit are parallel with each other. Correspondingly, the number of hand washes that occur during patient room visits increases over time. The effect of length of stay in patient room on HH performance is dominated in this analysis by the much larger sample of nurses. Future work will evaluate the effect of length of stay of different HCP groups.

One possible explanation for the decrease in patient room exit performance is that washes that happened more than 1 minute before exit are sometimes interpreted by staff as satisfying the environment exit wash requirement. Figure 1 further supports this, showing that staff washed 46.5% of the time before entering the patient room, but only 36.12% of the time before exiting. Systems that rely on only time constants to determine HH compliance presume that hand wash events that occur outside those time constants do not satisfy entry and exit opportunities when they might. A hand wash event that occurs more than 60 seconds before patient room exit does satisfy exit performance rules as long as nothing in the patient environment is touched before leaving.

Consecutive missed HH opportunities

Our results suggest that it would be valuable to monitor consecutive events, or chains of activities, by an individual HCP rather than observing HH in single events such as entering or leaving 1 room.

Manual auditing methods usually involve the auditor standing close to a patient room so that HCPs can be seen entering and leaving

the room and their HH actions can be recorded. If HH is missed upon room exit, then the HCP is typically not followed beyond line of sight to see what HH actions follow, thus ignoring consecutive missed opportunities by a single HCP.[22] We may be missing potentially important information using the traditional approach or any other method that does not collect individual participant data. Our results show that chains of missed opportunities are not infrequent; 83% of missed HH opportunities occur as part of a series of events, not in isolation (Fig 4).

Some of these chains of missed opportunities may be explained by accepted practice and are not considered by auditors to be missed HH opportunities. In our institution, the housekeeping staff wash, glove, and then perform some tasks moving room-to-room without removing gloves and washing. They empty waste baskets twice during the day shift and sweep daily. If there is a need to touch the patient environment in addition to the waste basket, then the staff are required to perform appropriate HH. Another case of accepted practice for a chain of missed HH occurs by unit aides who deliver and pick up meal trays to each patient room without washing and removing gloves between patient rooms. The premise is that the unit aide only touches the tray and nothing else in the patient environment. This is the same case for delivering water each day. Nursing staff on the night shift make room-to-room hourly rounds to check patients and may not need to touch the patient or patient environment.

The EMS used in this study was configured to reflect the institution's best practice guidelines, which direct all staff to clean their hands every time they enter or exit the patient room, regardless of whether they contact the patient or the patient environment. Therefore the EMS does not currently differentiate tasks exempt from HH procedures from those that are not, and results include such room-to-room task sequences by housekeeping and nursing staff.

To allow the EMS to identify a series of patient room visits that are exempt from HH procedures and to ensure that every patient room visit within the series is exempt, a measure based on known patterns of activities could be developed. Room visit duration can be used to help differentiate 1 type of task from another. Westbrook et al[23] show that for nurses, the mean task duration of direct patient care is 31% longer than for indirect patient care. By combining patient room visit duration with HCP group allocation, time of day, and the number of consecutive missed opportunities, it might be possible to classify patient room visits as requiring or not requiring HH.

Additional monitored areas

The EMS can be used to identify HH performance in specific locations or monitored zones other than the patient rooms. Activities performed in the soiled utility room may be as important as other areas owing to the potential for spread of infection because items that have been in contact with the patient or patient's environment are collected there. The soiled utility room on the nursing unit in this study housed a rolling rack on which plastic bags of dirty laundry are kept for pickup. Articles for high-level disinfection, a macerator, and sharps and biowaste containers are also located in the soiled utility room. Recognition by the facility of this area being at high risk of hand contamination is demonstrated by having a hands-free automatic entrance, 2 sinks in the room with soap dispensers at each, and an ABHR dispenser immediately outside the room.

Our results identified the same aggregate HH performance on exit from the soiled utility room as that with the overall patient room performance (67%), yet a soiled utility room might be expected to be a more hazardous environment. The soiled utility room should be included in audits and given the same importance as the patient environment. The ability of the EMS to record the location of HH in non-patient areas may help focus training and education programs to prevent the spread of infections.

We intend to extend analysis of these secondary measures to include further temporal and spatial factors such as additional monitored areas including clean utility and medicine rooms, time between patient room visits, the order of visits, and patterns of dispenser use.

CONCLUSIONS

The monitoring of time and place is central to calculating HH performance and can be used to extend our understanding of HH behaviors. The amount of time allowed by systems for staff to wash before and after entering and exiting the patient zone affects estimates of compliance. The definitions and impact of these time constants should be transparent to evaluators of technologies and staff participants. It is likely that extra washes performed inside the room before exit are sometimes perceived by staff as satisfying the exit washing requirement. This could be a result of unclear understanding of the time constants or a potential weakness of the EMS to identify hand washing events associated with patient room exit.

The high resolution of HH performance data collected by continuous monitoring of individuals shows that aggregate scores do not accurately reflect the HH practice of HCP groups and that the distributions of individual scores within HCP groups can vary greatly. Continuous individual monitoring also reveals the actual chain of risk of spreading infection via consecutive missed opportunities versus reporting of specific moments in isolation from others. Although some of these missed opportunities can be explained by institutionally accepted exemptions from standard HH practice, it is unlikely that decisions made about these exemptions were informed by high-resolution data that reveal the potential impact of those decisions.

Analysis of HH performance shows that different HCP groups on the same unit perform different tasks, spend different amounts of time in patient areas, and, in some cases, follow differing HH procedures. In addition to the patient environment, monitoring of HH compliance should include other locations such as the soiled utility room. Use of these measures should be considered when attempting to identify high-risk locations and activities, for developing targeted training and interventions and may lead to the establishment of HCP group-specific HH protocols.

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