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Major Article

Clinical experiences with a new system for automated hand hygiene monitoring: A prospective observational study

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Background: Hand hygiene compliance (HHC) among health care workers remains suboptimal, and good monitoring systems are lacking. We aimed to evaluate HHC using an automated monitoring system.
Methods: A prospective, observational study was conducted at 2 Danish university hospitals employing a new monitoring system (Sani nudge). Sensors were located on alcohol-based sanitizers, health care worker name tags, and patient beds measuring hand hygiene opportunities and sanitations.
Results: In total, 42 nurses were included with an average HHC of 52% and 36% in hospitals A and B, respectively. HHC was lowest in patient rooms (hospital A: 45%; hospital B: 29%) and highest in staff toilets (hospital A: 72%; hospital B: 91%). Nurses sanitized after patient contact more often than before, and sanitizers located closest to room exits and in hallways were used most frequently. There was no association found between HHC level and the number of beds in patient rooms. The HHC level of each nurse was consistent over time, and showed a positive correlation between the number of sanitations and HHC levels (hospital A: r = 0.69; hospital B: r = 0.58).
Conclusions: The Sani nudge system can be used to monitor HHC at individual and group levels, which increases the understanding of compliance behavior.

Despite an ever-ongoing focus, hospital-acquired infections (HAIs) are still one of the most common adverse events in health care delivery, affecting 7%-10% of all patients.[1-3] HAIs and spread of antimicrobial resistance can be reduced by improving hand hygiene compliance (HHC) among health care workers (HCWs).[4,5] However, it remains a challenge to achieve and sustain high HHC. A systematic review based on 96 studies found the median overall compliance rate of HCWs to be 40%, showing a large variation.[6]

HHC has been notably difficult to measure and there are currently several different monitoring methods being used.[7,8] Direct observation of hand hygiene by a trained observer is the most commonly used method, but only captures a small fraction of the total hand hygiene events while also being time-consuming and subject to bias

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(observer, observation, and selection biases).[7,9] Research has shown that HHC declines significantly when the HCWs do not feel as though they are being observed.[10]

Technological advancements have made automated and continuous HHC monitoring possible.[11,12] Automated systems collect significantly more hand hygiene events compared with direct observations and can be done 24 hours per day. This enables real-time data to be provided without requiring unnecessary expenditure of staff hours.[11,13] Differentiation in situational hand hygiene opportunities is an important factor for an effective implementation of automated HHC monitoring systems,[14] but most monitoring systems are only able to measure patient room entries and exits, contributing to a limited picture of the true hand hygiene behavior.[12] In addition, no systems appear to measure HHC at ward levels while combining data with the types of rooms (functionality) and the change of HHC over time on an individual level (intraindividual variability). Such insights could be used to personalize hygiene education and help HCWs perform hand hygiene at the right time and in the areas of the wards where it is needed.

As part of a Danish quality improvement project, we developed and tested an advanced, electronic monitoring system capable of (1) measuring HHC both at individual, group, and ward levels; (2) measuring HHC in all types of hospital rooms in a connected manner, that is, taking previous workflow into account and not looking at HHC as isolated situations; and (3) measuring nurse-patient contact in patient rooms. The system (Sani nudge system; Sani nudge, Copenhagen, Denmark, https://saninudge.com. Accessed Oct 15, 2019) uses a network of sensors and real-time location to perform indoor positioning in the hospitals. Based on the principle of the World Health Organization (WHO) "5 Moments for Hand Hygiene,"[15] the system uses algorithms to analyze and provide HHC results in real-time (see Methods section).

Using this automated monitoring system, we aimed to assess the HHC of HCWs in different types of hospital rooms and in single versus multiple bed patient rooms. On an individual level, we aimed to evaluate the association between HHC and time spent in the patient zone, as well as the consistency of the HHC levels over time. We also investigated the correlation between the number of sanitations and HHC to understand if HCWs, who sanitize the most, also have the highest HHC levels or if they are spending time on cleaning hands in situations in which it is not needed.

METHODS

Study design and setting

This prospective, observational study and quality improvement project was conducted from February 1, 2018 to December 31, 2018, in an orthopedic surgery department (29-beds unit, Bispebjerg University Hospital, Capital Region of Denmark [hospital A]) and in an oncology department (17-beds unit, Aarhus University Hospital, Central Denmark Region [hospital B]). According to Danish law, approval was queried and subsequently evaluated as not needed by both the ethics committee (J. no. H-16020755) and the Danish Data Protection Agency (J. no. 2018-312-0169).

Automated hand hygiene monitoring system

The automated hand hygiene monitoring system (Sani nudge system) is a real-time location system measuring HHC 24/7, and consists of sensors located on all alcohol-based handrub dispensers (sanitizers), name tags of the HCWs, and near the patient beds, creating a network that measures hand hygiene opportunities and sanitations in all rooms of the wards. The network of sensors enables the system to track the HCWs as they go around in the wards, and takes situations and behavior leading up to and after sanitations into consideration when calculating HHC.

How the system works

(1) The Sani ID is a discreet sensor located on the HCW's name tag and has a battery life of 2 years. The Sani IDs continuously track the movements of the HCWs and registers each hand hygiene opportunity. The sensor is able to provide the hygiene department and hospital management with HHC data stratified according to profession (for example, nurses, nurse assistants, physicians, physiotherapists, cleaning assistants, porters, bioanalysts, secretaries, and others). (2) The Sani sensor is located on all sanitizers in the wards and records dispenser usage. A nudging feature can be enabled (although not activated during this study) when compliance decreases, which results in increased focus toward the sanitizers, avoidance of campaign fatigue, and improved adherence to hand hygiene guidelines. (3) In the patient rooms, a patient clean zone[7] around each bed is created by a bed sensor that is used to register whether hand hygiene using alcohol-based handrub has been performed before entering and after exiting the area. This allows the system to be used as a proxy for monitoring WHO moments 1 (before touching a patient), 4 (after touching a patient), and 5 (after touching patient surroundings).[15] In clinical practice, the majority of moments 2 (before clean/aseptic procedures) and 3 (after body fluid exposure/risk) will also be part of the recordings because these procedures will be performed in the patient zone. The system does not measure physical contact but uses clinically validated, probability-based algorithms based on time and distance measurements in the patient zone to calculate if contact has taken place. The system is dynamic, which means that it does not look at HHC as isolated situations but takes previous workflow of the HCW into account. This allows for different national and local guidelines to be used if needed.

The data are anonymized, and the algorithms used to calculate HHC are based on the guidelines of the WHO "5 Moments for Hand Hygiene,"[15] and have been validated and compared with direct observations (data available on request). Since 2016, pilot studies were conducted in the 2 hospitals in a limited number of rooms. Data from these pilot studies were used to develop the monitoring system and were verified using video cameras.

Study subjects and data collection

HCWs with direct patient contact and daily ward activity were eligible for this study. Only nurses were included here as the other staff groups did not have daily connection to the chosen wards, thus preventing accurate comparisons and examination of hygiene behavior between the individuals. Participation in the study was voluntary and anonymous, and the HCWs were briefed about the study purpose and the placement of the sensors. The study focused on HHC using alcohol-based hand disinfection.

The first 5 months of the study period were dedicated to test different types of sensors and functioned as a baseline period to minimize the risk of confounding by the Hawthorne effect.[16] Data generated in this period are therefore not included in the analyses.

Statistical analysis

Ward-specific HHC data were obtained from the automated hand hygiene monitoring system and provided as HHC rates (0%-100%). We assessed correlations by the Spearman rank correlation tests. Data were aggregated for the study period, and descriptive statistics were applied and displayed using Microsoft Power BI software version 2.66.5376.2521 (Microsoft Corporation, Redmond, WA).

RESULTS

In total, 42 nurses (hospital A: n = 17; hospital B: n = 25) were included. The system registered an average of 466 hand hygiene opportunities per ward per day, and the average HHC was 52% and 36% in hospital A and B, respectively. Most nurse-patient contacts took place between 8:00 AM and 12:00 PM (hospital A: n = 10,590; hospital B: n = 12,916), whereas the fewest occurred between 12:00 AM and 4:00 AM (hospital A: n = 3,201; hospital B: n = 1,526). A similar pattern was observed for the HHC with the highest levels found during the mornings (hospital A: 52%; hospital B: 31%) and subsequently decreasing throughout the day, reaching the lowest levels during the night shifts (hospital A: 37%; hospital B: 28%).

HHC in the specific rooms

The heatmaps illustrated a disparity in HHC levels with sanitizer according to room types and functionality with the lowest level of HHC in patient rooms (hospital A: 45%; hospital B: 29%) and the highest HHC in staff toilets (hospital A: 72%; hospital B: 91%) and sluice rooms (hospital A: 84%; hospital B: 66%) (Fig 1). The sanitizers located in staff toilets, sluice rooms, and kitchens were more frequently used than sanitizers in offices, patient rooms, and patient toilets (Fig 1). In addition, the sanitizers located at a greater distance to the exit of the rooms were used less frequently than the ones closest to room exits and in the hallway of hospital B (Fig 1).

The HHC levels with sanitizer did not vary between patient rooms with single, twin, or multiple beds, but markedly between hospital A and B (Fig 2). For both hospitals, however, HCWs more often remembered to sanitize hands after rather than before patient contact (hospital A: mean HHC of 56% vs 46%; hospital B: mean HHC of 37% vs 32%).

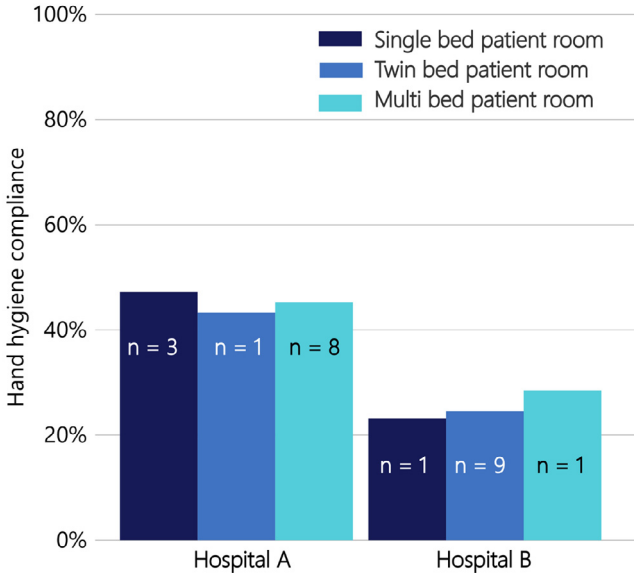

Fig 2. Hand hygiene compliance of the health care workers according to the number of beds in the patient rooms. Compliance is calculated as an average during the study period. All multibed patient rooms included had 3 patient beds. *N*, number.

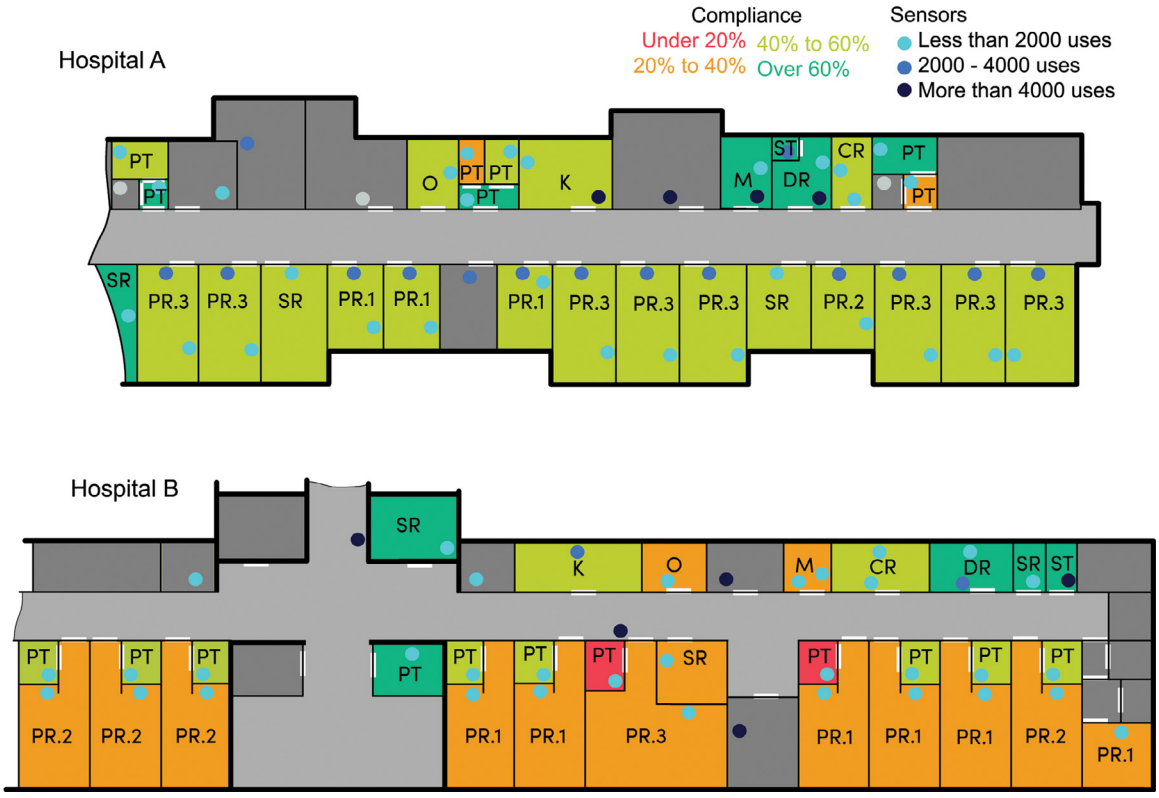

Fig 1. Heatmaps of the hand hygiene compliance and sanitizer usage in the wards of hospital A and B during the study period. The heatmaps are graphical representations of data that uses a system of color-coding to represent different values of hand hygiene compliance and sanitizer usage. The color in each room illustrates the average compliance range during the study period (refer to the legend). The circles indicate location of the sanitizers, whereas the colors illustrate the amount of time being used in absolute numbers (refer to the legend). Only hospital B had sanitizers located in the hallway. Gray colored rooms (staff office, meeting and storage rooms) were not included in the study as agreed by the hospitals. White bars indicate location of doors. *CR*, clean utility room (sluice room for storage of clean goods); *DR*, dirty utility room (sluice room for soiled goods); *K*, kitchen; *M*, medication room; *O*, office; *PR.1*, patient room (1 bed); *PR.2*, patient room (2 beds); *PR.3*, patient room (3 beds); *PT*, patient toilet; *SR*, storeroom; *ST*, staff toilet.

HHC on an individual level

HHC with sanitizer was consistent over time on an individual level, meaning that high-performance HCWs consistently performed well, whereas low-performance HCWs consistently performed poorly (Fig 3).

We also found that the HCWs who had the lowest HHC performances tended to spend less time in the patient zone (in the patient rooms) compared with those with higher HHC levels (Fig 4).

Finally, there was a positive correlation of moderate strength between the number of sanitations and HHC levels (hospital A: r = 0.69; hospital B: r = 0.58), showing that those who sanitize many times during a shift also tend to have high HHC levels (Fig 5). However, there were also cases in which some of the HCWs, who sanitized the most, had low HHC levels.

DISCUSSION

From the data gathered by the automated hygiene monitoring system, we have exposed the possibility of measuring HHC with sanitizer at individual, group, and ward levels. This in turn gives the hospitals an essential tool in understanding the areas where poor compliance behavior mostly occurs. Specifically, we found that rooms related to unclean procedures (toilets and sluice rooms) had much higher HHC from all HCWs. The example extends to the hand hygiene around the patient beds, showing higher compliance after having come in contact with a patient rather than before, which might be related to the feeling of being soiled.[17] This is further supported by our finding of HCWs who spent less time in the patient zone had the lowest HHC performances. The brief contact with the patient and their surroundings may lead to the belief that there has been no contamination of the hands. The consistency between the results obtained from this study and that from the literature[6] adds to the strength of the external validity and supports the usefulness of the system.

Other well-known factors associated with the levels of HHC are staff profession, workload, and location of sanitizers.[6,18–20] The results in this study support that location of sanitizers plays an important role for HHC levels, as sanitizers closest to room exists and in easily accessible places such as the hallways were used the most. This brings critical insight to hospitals, further underlining the requisite of placing sanitizers within reach and as part of the natural workflow.

To our knowledge, only one other study has evaluated factors related to hand hygiene by using an automated, continuous hand hygiene monitoring system based on opportunities according to the WHO "5 Moments for Hand Hygiene."[21] That study was limited by only investigating HHC in few patient rooms, and only focusing on hand disinfection prior to potential patient contact. In addition, it did not calculate if a HCW came directly from another room (eg, kitchen, medication room, sluice room) and had sanitized when leaving that room. The strength of the Sani nudge system is the dynamic and intelligent sensor network that can track HCWs' movement between rooms and wards, while taking workflow and sanitizing behavior leading up to a hand hygiene opportunity into account. However, it is a limitation that the system only measures contacts in patient rooms when the patient is in bed, and that the registered contacts is an estimate of the likelihood of staff directly touching the patient.

Some other limitations must also be considered. First, this study could be subject to potential bias because of the observational design and inability to control for unknown confounders. Second, we did not measure handwashing procedures, which could add relevant information to the hygiene behavior. Even though the HCWs had low HHC in terms of sanitation using alcohol gel, they might have washed their hands with water and soap and omitted the use of alcohol gel,

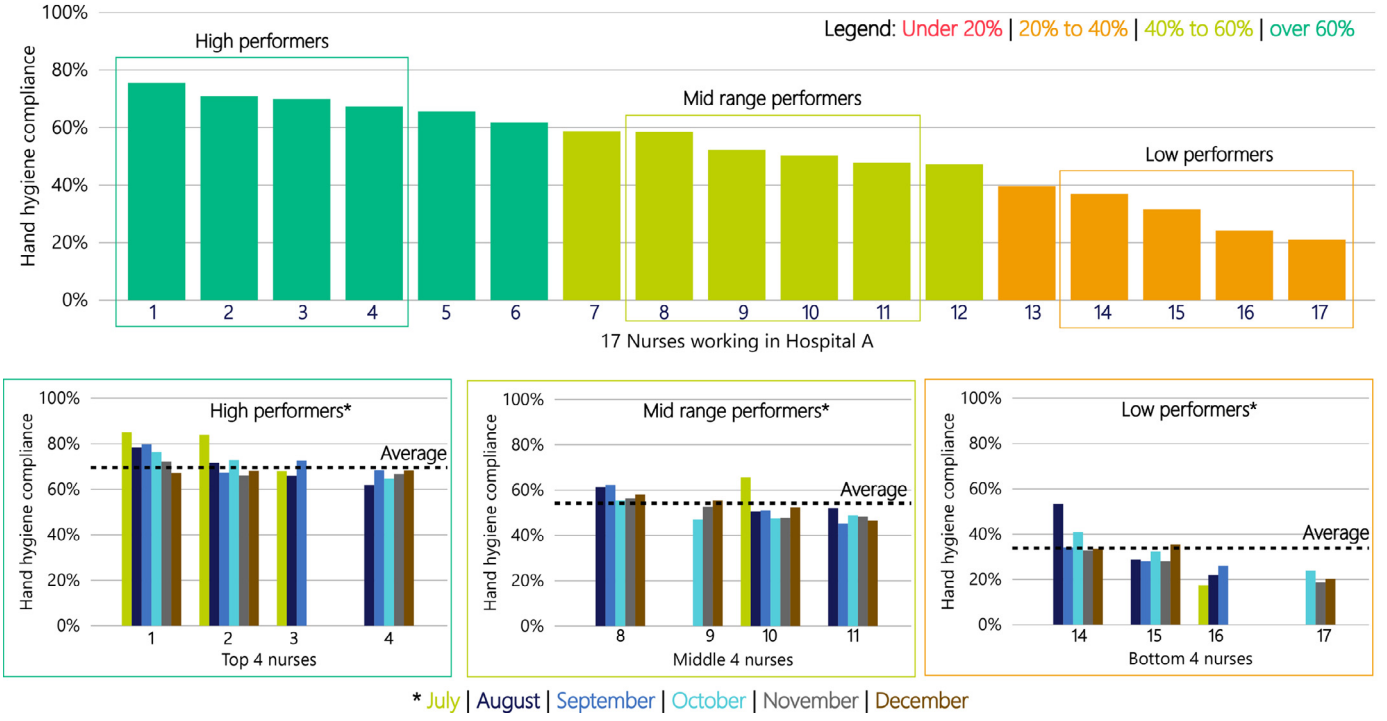

Fig 3. Average hand hygiene compliance of the health care workers on an individual level and stratified into high, mid-range, and low performers in hospital A. Hand hygiene compliance is calculated as an average during the study period (upper figure) and on a monthly basis (lower figures). The hand hygiene compliance of the 4 high, mid-range, and low performer health care workers are displayed in separate figures.

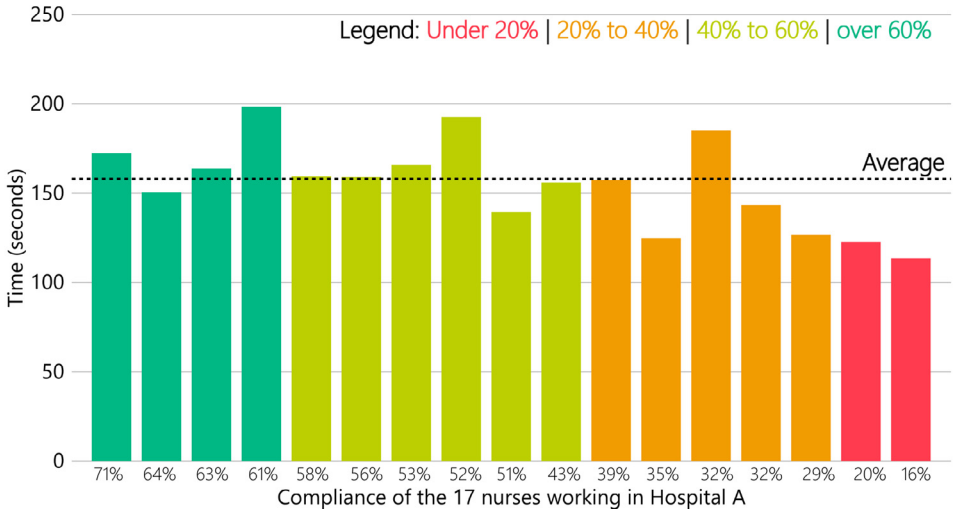

Fig 4. Association between the average hand hygiene compliance of the health care workers in the patient zone in the patient rooms, and the average duration of the visits in hospital A. Hand hygiene compliance for each of the nurses is illustrated as an average during the study period. The dotted line illustrates the average time spent in the patient zones.

even though that was part of the guideline. The system is, however, capable of measuring handwashing procedures, but that was not the scope of this study. Third, the system does not measure the quality of the hand disinfection procedure or capture all hand hygiene opportunities arising in a ward. Thus, HHC levels should be interpreted with this in mind and preferably correlated to infection rates if possible. It should also be noted that a small number of study participants (n = 42) were included and limited to nurses. The observed hygiene behavior and results might not be representative for other health care providers. The system is, however, capable of measuring HHC levels in the different types of professions, and can stratify results according to that. A future, larger study will look into this together with HHC levels of patients and visitors.

This is, to the best of our knowledge, the first study to show that heatmaps can be used to generate an overview of the hygiene situation at ward levels, and might be a future tool for hospitals to increase the levels of HHC. The highest and the lowest HHC with sanitizer were found in staff toilets and patient rooms, respectively. The patterns of HHC levels were similar in the wards of both hospitals, indicating that these findings might be applicable to other hospitals as well. These results are particularly interesting because limited information exists on HHC in staff toilets, as direct observations cannot be used due to privacy reasons.

As expected, we found that the HCWs who sanitized the most also had the highest HHC levels. However, we also identified a few individuals who had low HHC levels despite high sanitation rates. This is interesting because it indicates that these individuals are sanitizing without having been in a situation in which it was required according to the hygiene guidelines. Such data can be used as an opportunity to identify and help staff who might benefit from a recap of these guidelines. Interestingly, the heatmaps (Fig 1) revealed a similar pattern, showing that a high number of sanitations in some patient rooms did not result in high HHC levels in the same rooms. This demonstrates that the number of sanitations itself is not an ideal marker of the HHC levels, and that electronic monitoring systems must be able to also measure hand hygiene opportunities to avoid overestimating the hygiene performance. This is possible with the Sani nudge system, which makes it an interesting tool for the hospitals.

In this study, we have identified a pattern showing that if an HCW had low compliance in one room, they would most likely have it in other rooms as well. In addition, this pattern of individual hygiene performance remained consistent over time, which is important knowledge because it shows that hospitals should consider an individualized approach to significantly increase the overall HHC and meet the hygiene goals. A natural next step with this system would therefore be to use the data to identify individual needs and tailor e-learning sessions based on this. Moreover, it would be possible to test the effectiveness of different interventions, such as nudging, personal feedback, campaigns, and others, both on short and long term.

Conflicting results exist in relation to HCWs' hygiene behavior in single versus multiple bed patient rooms, especially in surgical and general medicine departments.[22-24] It has been hypothesized that the risk of HAIs or the transfer of pathogenic microorganisms between patients is increased in patient rooms with multiple beds due to low HHC as the HCWs go from "bed to bed" without sanitizing. We did not find such an association in this study, and it could indicate that HCWs recognize the necessity of sanitizing in-between bed visits and not solely between room visits. However, this study only included a few single bed patient rooms, thus limiting the number of observations and increasing the risk of type 2 error. Despite this, we have shown that it is possible to measure HHC in the different types of patient rooms, but a future study with a larger setup is needed. The data are, however, relevant because many hospitals are currently considering whether to build more single bed patient rooms based on the earlier mentioned hypothesis.

CONCLUSIONS

The automated hand hygiene monitoring system proved to be a useful alternative to direct observation by trained observers, supplying detailed information about HHC with alcohol-based handrub on individual, group, and ward levels. We identified factors of relevance to HHC levels, which adds to the understanding of poor compliance behavior. HHC of each HCW was consistent over time, emphasizing an opportunity for hospitals to reach hygiene goals with individualized interventions based on data generated by the system. Finally, this study adds to the cumulative knowledge about the potential value of automated hand hygiene monitoring systems.

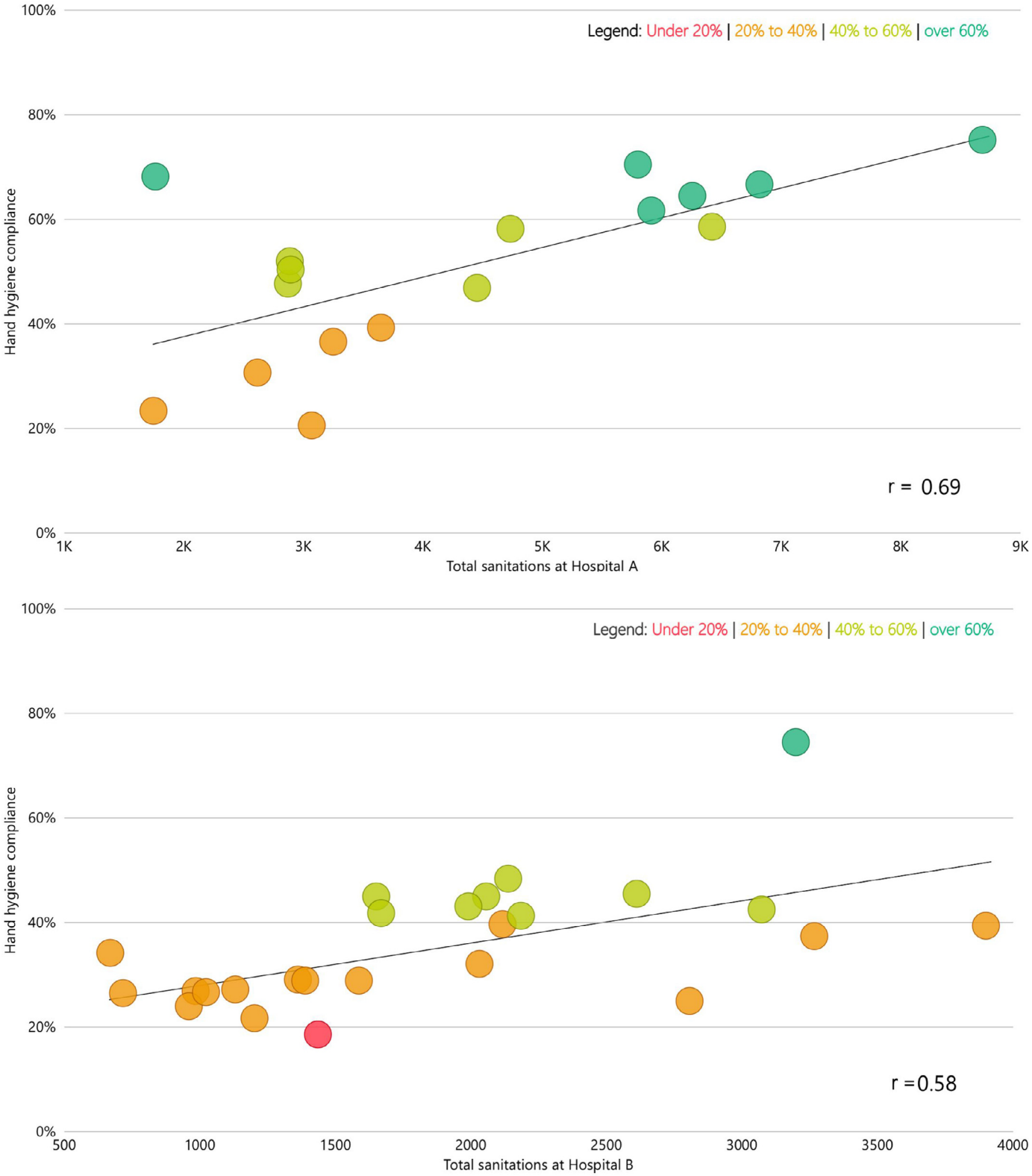

Fig 5. The Spearman rank correlation between number of sanitations and hand hygiene compliance levels in health care workers in hospital A and B. Hand hygiene compliance for each of the nurses is illustrated as an average during the study period.

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