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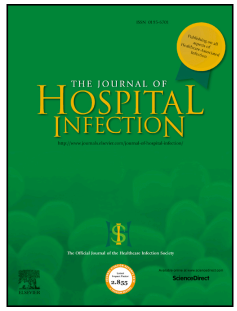

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FEASIBILITY OF A REAL-TIME HAND HYGIENE NOTIFICATION MACHINE LEARNING SYSTEM IN OUTPATIENT CLINICS

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SUMMARY (250/250)

Background

Various technologies have been developed to improve hand hygiene (HH) compliance in inpatient settings; however, little is known about the feasibility of machine learning technology for this purpose in outpatient clinics.

Aim

To assess the effectiveness, user experiences and costs of implementing a real-time HH notification machine learning system in outpatient clinics.

Methods

In our mixed methods study, a multidisciplinary team co-created an infrared guided sensor system to automatically notify clinicians to perform HH just before first patient contact. Notification technology effects were measured by comparing HH compliance at baseline (without notifications) with real-time auditory notifications that continued till HH was performed (intervention I) or notifications lasting 15 seconds (intervention II). User experiences were collected during daily briefings and semi-structured interviews. Costs of implementation of the system were calculated and compared to the current observational auditing program.

Findings

Average baseline HH performance before first patient contact was 53.8%. With real-time auditory notifications that continued till HH was performed, overall HH performance increased to 100% ($p < 0.001$). With auditory notifications of a maximum duration of 15 seconds, HH performance was 80.4% ($p < 0.001$). Users emphasized the relevance of real-time notification and contributed to technical feasibility improvements that were implemented in the prototype. Annual running costs for the machine learning system were estimated to be 46% lower than the observational auditing programme.

Conclusion

Machine learning technology that enables real-time HH notification provides a promising cost-effective approach to both improving and monitoring HH, and deserves further development in outpatient settings.

INTRODUCTION

Hand hygiene (HH) is widely recognized as the most effective way to reduce the transmission of healthcare-associated infections (HAI).[1-3] The consensus on how to best improve HH is a multimodal approach that addresses at least five elements: education of clinicians; HH notifications in the work environment; the position and type of hand disinfectants in relation to HH convenience and effectiveness; staff culture change pertaining to HH by involving healthcare leaders; and monitoring compliance with the HH guidelines and providing feedback.[1]

Additionally, HH compliance needs to be monitored to assess changes in performance over time. However, mainly due to limitations with the monitoring, it is difficult to obtain high quality evidence on the effectiveness of HH interventions.[4,5] Direct, discreet observation of HH compliance is considered the gold standard.[6] However, less than 1.5% of all HH opportunities are observed in practice because of the high demands on manpower resources.[6] Additionally, most observations are subject to the Hawthorne effect: healthcare professionals who are aware that they are being audited are likely to display more compliant behavior. [7] Performing regular covert observations to circumvent the effect is difficult in daily practice. This Hawthorne effect has been shown to bias HH compliance rates by 28% to 65%.[8,9]

Over the last decade**,** various studies have utilized technology to improve HH monitoring.[10,11] The applied technologies can be divided into two categories: technologies that monitor a specific aspect of HH (e.g. HH at room exit and/or entry, number of soap dispenses), and compliance monitoring technologies that assess both the number of HH opportunities and clinicians' compliance, for example by using video monitoring.[12,13] Compliance monitoring machine learning systems have been shown to effectively increase HH compliance, especially when combined with personalized real-time notifications (e.g. vibrations in nametags).[14] Most systems studied depend on wireless tracking technologies as radiofrequency identity tagging (RFID), wireless local area networking (Wi-Fi) or bluetooth low energy (BLE). As these wireless systems require both clinicians and patients to continuously wear a sensor or tag, its human-factor dependency is large. Most studies describe only prototypes, and we are not aware of any published large-scale implementation results. There are also concerns reported regarding electromagnetic interference (EMI), high costs and intensive maintenance.[15, 16] EMI from radio frequency identification has been reported to potentially induce incidents with existing medical equipment.[15]

Traditionally, these systems have been developed for the inpatient setting, with its specific design for longer-term stay and patient-clinician work flow. [16] However, the volume of outpatient care is globally on the rise and the frequency of patient-clinician contacts is high in outpatient settings.[17] Compliance with HH guidelines is hence important for outpatient care as well; this is emphasized by both the WHO and the CDC.[18-20] The cause and effect relationship between HH and HAI is, however, more difficult to examine in outpatient care, mainly because of uncertainty in distinguishing HAI from community-acquired infections. Currently, there is little knowledge about the feasibility of HH technology in outpatient settings.

We therefore developed and evaluated a real-time HH notification system suitable for the outpatient setting. This machine learning system uses infrared and pressure sensors to determine patterns indicating whether the clinician performs HH prior to first patient contact.[21] The hypothesis is that HH behaviour improves most when clinicians are reminded just-in-time, which is defined as just before actual patient contact using both audio and visual notifications. Additionally, the system records the HH compliance to monitor this over time. The aim of this pilot study was to determine the effectiveness, feasibility and costs of implementing the HH notification machine learning system in an outpatient setting, with special interest in the effects of real-time notifications.

METHODS

Study design and setting

We performed a mixed methods pilot study in the paediatric outpatient clinics of an academic medical centre in Singapore to analyse the effectiveness, costs and user experiences of the real-time HH notifications system. The system was piloted during consultations performed by nine clinicians, who were personally informed about the study and given information leaflets prior to the start of each session. They participated voluntarily and could opt out at any time. Data on HH compliance, including just-in-time compliance, was collected and compared during the baseline (real-time notifications inactive) and intervention periods (real-time notifications active). We projected the effects of the intervention-related HH compliance on nosocomial influenza-like illness based on previously published infection rates.[22] Additionally, user experience data was collected during daily briefings and interviews. The costs of the real-time notification system were compared to the current practice of an observational auditing program. An overview of the timeline is shown in Figure 1.

Current practice

Observational auditing is the current practice for providing insights into HH compliance. It is used to determine whether HH compliance changes over time, whether it differs between departments and whether HH improvement interventions are effective. Auditors are trained to observe HH as per the WHO Five Moments for Hand Hygiene.[1] The costs for the observational auditing program arise from the manpower required to perform the audits, reporting, logistics, support, and training of auditors. These activities are performed by staff from the infection control or nursing departments. The number of man-hours was calculated by the infection control team and the salary costs were based on the 2017 wages of nurses provided by the financial department of the hospital.

Intervention

The notification system was developed in conjunction with the engineering department of the National University of Singapore, with the main aim of directly influencing HH behaviour using real-time notifications in outpatient settings. Additionally, the system is able to record the HH compliance data of all outpatient sessions for retrospective analysis.

To perform these functions, the system needs to identify the HH opportunities, identify when HH is needed, alert the physician via notification, track when HH is performed and whether HH is performed at the appropriate time. HH opportunities were defined as the first movement of a clinician into a zone around the patient, analogous to the HH "prior to patient contact" opportunity as defined for observational monitoring. This zone, and movement into it, is identified using infrared technology (Sharp ® sensor GP2Y0A710K0F). Pressure plates (RS ™ Pro Pressure Pad, with 16kg over $50mm^2$ actuation pressure) were implemented to detect the presence of a patient sitting on the consultation room chair or lying on the patient couch. HH compliance, defined as the pressing down of the hand-disinfectant dispenser to dispense liquid on the clinician's hands, was tracked using pressure sensors fitted under the dispensers (Interlink® Electronics Force Sensitive Resistor (FSR) 400, with added capacitive impedance). The processor determined the timings and the activations of the two notifications: visual and auditory. The visual, proactive notification was a diffused 10 mm red LED, and the auditory notification was a beeping sound to notify clinicians to perform just-in-time HH if no HH was performed at the initial opportunity. The setup of the real-time notification system is displayed in Figure 2.

Two prototypes of the real-time notifications system were developed as part of the pilot study. The first prototype was used to test the technical aspects in practice and to provide feedback used for development of the second prototype. The main improvements were in the technical set-up and the real-time notification. In both versions, the just-in-time auditory notifications were activated if no HH was performed at the initial opportunity. The prototypes started recording the HH opportunity from when a patient first activated the pressure sensor on either the chair or the examination couch.

Data were collected using the second version of the prototype in three separate periods, one baseline period and two intervention periods. During the baseline period, the prototype was set up to collect data but with all notifications inactive. In the intervention periods the system was implemented with both visual and auditory notifications active. In the first intervention period, the auditory notification would continue until the physician performed HH and would be recorded as compliant. For the second intervention period, the auditory notification was set to stop after 15 seconds and HH would be recorded. Non-compliance is determined when there is no HH performed for two minutes after the start of the notification. The system registered the HH opportunity as compliant if the dispensers were used prior to the HH opportunity. HH compliance was collected in three periods using the second version of the prototype. The same nine physicians were observed over the three periods. Overall, data collection occurred over three months in a paediatric surgical outpatient clinic.

OUTCOME MEASURES

Primary outcome measure - Hand hygiene compliance

The real-time HH notification machine learning technology monitored when HH was performed and whether this was prior to, or after the notification. Differences in compliance rates were tested with the two proportion z-test.

Secondary outcome measures

Just-in-time hand hygiene compliance

The just-in-time HH compliance was defined when no HH compliance is performed prior to the physician moving into the patient zone, but within 20 seconds after crossing the IR line. This timing gives the physician sufficient time to respond to any notification by the real-time notification system. The definition of just-in-time compliance was the same for all phases of the study.

Costs

The costs for full implementation of the system were calculated based on materials and labour needed for initiation, maintenance and support. The costs were extrapolated based on the development of the prototype, with additional expert opinion from the infection prevention team and financial department. The number of notification systems required was calculated based on the outpatient clinic visits and turnover in 2016. The costs were estimated for full implementation in all paediatric outpatient clinics (n = 37) within the hospital. All costs were determined in 2016 US dollars. The salary costs were calculated to be $45.92 per hour.

User experiences

Information on user experiences was gathered throughout the study by collecting the feedback from the clinicians and engineers. Additionally, four semi-structured interviews were conducted with two physicians, one nurse and one infection prevention specialist. These interviews focused on how clinicians perceived the notifications system, HAI, HH and the Hawthorne effect in outpatient care. The interview template is shown as Supplement 1. The interviews took up to half an hour and were analysed ad verbatim.

Healthcare associated infection projections

As the goal of HH compliance is to lower the HAI rate, we projected the effect of the just-in-time compliance on the HAI rate if it were to be implemented in all the paediatric outpatient clinics. The HH compliance from both intervention periods were combined and subsequently compared to the baseline period for the projections. A study by Simmering et al. showed that visits to outpatient care by healthy children were associated with a subsequently increased risk (by an average of 54%) of influenza-like illnesses (ILI) in a family member over the ensuing 2 weeks.[22] There was an average 3.17% increase in the probability of an ILI office visit in the week of or 2 weeks following a well-child visit to outpatient care. No evidence on other infection rates within the outpatient setting was available from published literature.

Considering the relationship between HH and HAI, evidence from inpatient settings indicates that the HAI rate is 0.18% to 0.38% lower per percent increase in HH compliance.[23,24] For outpatient settings, we assumed the lower and upper bound of the relationship to be 0.05% and 0.30% HAI/HH, respectively, and that the effect of HH on the HAI rate is linear. Also, this is under the assumption that the patient is only exposed to the clinician, which is generally true as the other staff members are handling the paperwork and not directly involved in the clinical sessions. Additionally, we assumed that the effect of the intervention would be the same when implemented in all outpatient clinics, and that the impact of the just-in-time compliance is comparable to general HH compliance. The calculations were based on the number of outpatient paediatric clinic visits in 2016 (n = 228,716).

Statistical analysis

All results are reported as the average with 95% confidence interval (95%-CI); the median, 25th and 75th percentile of the distribution were presented when appropriate. The sensitivity of the HAI projections was assessed by incorporating the uncertainty in the appropriate parameters and bootstrapping the analyses for 10,000 replications. Statistical analyses were performed using Microsoft Excel 2007.

RESULTS

Primary outcome

Hand hygiene compliance

HH outcomes are summarized in Table I. The real-time notification prototypes recorded a total of 313 HH opportunities, 80 during the baseline period and 243 during the intervention periods (95 during intervention I and 138 during intervention II). Mean HH compliance during baseline was 53.8% and 100% during intervention I ($p < 0.001$). For intervention II, the mean HH compliance was 80.4%.

Secondary outcomes

Just-in-time hand hygiene compliance

Of the HH opportunities, 27.9%, 44.2% and 28.03% were just-in-time compliant for the baseline, intervention I and intervention II, respectively. The differences were 16.3% ($p = 0.034$) in between baseline and first intervention; and 16.2% ($p < 0.001$) in between first and second intervention.

Costs

Table II provides an overview of the parameters and associated costs. The observational auditing programme required 1,289 hours (or 0.62 FTE) to perform the audits, reporting and training of the auditors. The total annual running costs were $59,210.

The total cost of materials for each system prototype was $340.89. The number of systems required hospital-wide depended on the number of paediatric outpatient patients (n = 228,716 based on 2016 data), patient turnover within a consultation room (three patients per hour) and how many hours the outpatient clinics are open annually (2,088). This resulted in a minimum number of rooms and therefore systems required of 37. The total material costs for full implementation were $12,613. In total, the annual costs for the real-time notification system were estimated to be $27,419 (46%) lower compared to observational auditing in the paediatric outpatient setting.

User experiences

The nine clinicians who participated were aware of HH as one of the most important safety measures to prevent HAI. However, they indicated that HH is sometimes forgotten because they were often too busy, combined with the low risk perception of HAI in outpatient care as patients are relatively well and non-contagious. They agreed that the real-time notification system has the potential to improve HH.

During the testing of the first version of the prototype, all but one of the clinicians participated in the pilot study. It was more difficult than anticipated to set up the infrared line between the physician and the patient. Attaching the detachable sensor system underneath the consultation table, proved to be difficult as the patient or clinician could accidentally knock against it such that it could fall. These issues were rectified with the second prototype.

Based on users' feedback, the second prototype improved on the ease of use, reliability, set up, and how components were incorporated into the workflow, existing furniture and dispensers. Users' experiences became more positive when reliability on these aspects was improved. Some concerns about long-term sustainability, clinician fatigue to repeated notifications, and accuracy of the prototype for auditing HH compliance were raised. All physicians agreed that further research would be valuable in providing insights into the effects of this notification and auditing tool in other outpatient settings and over a longer period.

Healthcare associated infections

The average HH compliance during the intervention periods was 34.6% higher compared to the baseline period (88.4% vs 53.8%). Based on the increased infection risk of 3.17% and the average estimate of the HAI-HH relation of 0.175%, 7,250 episodes of nosocomial ILI could result from the annual 228,716 paediatric outpatient clinic visits. The estimate for the number of prevented ILI by the increase in HH compliance was 440 per annum.

DISCUSSION

This study demonstrated that a real-time HH notification machine learning system was able to increase HH compliance in outpatient clinics by almost two-fold. Relative to the full implementation, when a notification with lower intensity and duration was activated, the HH compliance was reduced by 20%. The system also increased just-in-time HH compliance by 17% and was estimated to prevent 440 ILIs per annum associated with paediatric patients visiting outpatient clinics. Additionally, the real-time notification system provided the opportunity to audit all HH opportunities, at a relatively low cost compared to the current gold standard of observational auditing. The application of the system in our clinics would cost 46% ($31,791) less on an annual basis. Performing full time audits with the real-time notification system has other advantages. Firstly, the quantity of data on HH compliance would increase, and it reduces the Hawthorne effect by integrating the audits into daily practice. Secondly, the real-time notification system puts additional focus on the time relation between performing HH and touching the patient. This is important as earlier studies have indicated that timely HH is associated with decreased hand contamination.[25,26] Additional studies are needed to confirm that just-in-time HH can prevent HAI. Thirdly, we were able to use the system to estimate the effect of HH on the number of ILI prevented, and it is highly plausible that the infection rates of other nosocomial infections would also be decreased. Overall, this study adds to the evidence about HH practices in paediatric and outpatient settings, where evidence is currently lacking.[27]

The development of the system has several impacts on quality improvement. To our knowledge, this study is the first publication of a HH notification and monitoring system in the outpatient setting. Other technologies have been developed to track HH compliance and have shown positive effects; however, most are developed for the inpatient setting and are highly human-factor dependent as staff and patients need to wear (RFID) tags. As the outpatient setting serves an increasing number of patients, more focus on HH in that setting is justified. Furthermore, the real-time notification system represents a novel interpretation of the first moment of the WHO guidelines.[28] Incorporating the timeliness of HH in the definition of compliant HH using machine learning can make monitoring more effective. Of course, the real-time notification system can also be adopted for implementation in the inpatient setting, where it would still have the advantage of being embedded in the healthcare environment. Novel approaches in auditing, practical interpretations of existing WHO HH guidelines and encouraging the healthcare workforce to be actively involved in performing HH will help improve the quality of care.

There are several limitations of this study. Firstly, as the inactive notification setting functioned as the baseline, there was no clean control setting to help determine the detailed effect on HH compliance.

There were observational audits in the hospital at the time of the study, but direct comparisons of HH compliance were likely to be invalid as the number of direct observations in the specific rooms was low, and the definitions were not similar. Secondly, data collection on HH was performed in a relatively short period in this pilot study. As the effects of an HH intervention are often dynamic over time (e.g. resulting from increased awareness and Hawthorne effect in the short term, or become accustomed and adapted in the long term), the prolonged effects might differ from our results. Thirdly, there were several assumptions that underlie the HAI projections; most notably, the infection rates in the outpatient setting and the relation between HH and the infection risk, but also the fact that the clinician crossing into patient zone was having direct patient contact, and that the pressure sensor was detecting a patient sitting down and not the caregiver or bags. Finally, the costs analysis was based on retrospective estimations i.e. the number of hours spent on auditing were not tracked in person. A longer, controlled, study with a market-ready version of the system that is implemented in all clinics would improve the costs estimation of the intervention. The cost analysis of the observational auditing program can be improved by a prospective study to document actual time spent on auditing.

In conclusion, real-time notification machine learning technology for HH provides a promising cost-effective approach in both improving and monitoring HH, and deserves further development for outpatient settings.

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CONFLICT OF INTEREST STATEMENT

None declared

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None specific to this study

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Table I Hand hygiene opportunities, overall and just-in-time compliance

	HH opportunities (n)	Overall HH compliance (%)		Just-in-time HH compliance (%)	
Baseline	80	53.8		27.9	
Intervention I	95	100.0		44.2	
Difference from Baseline [p-value]		46.2	[<0.001]	16.3	[0.034]
Intervention II	138	80.4		28.0	
Difference from Intervention I [p-value]		-19.6	[<0.001]	16.2	[<0.001]

Table II Cost estimates (per annum) of the real-time notification system for hospital-wide HH compared to observational auditing

Element	Units	Costs	Total costs
Observational auditing program			
Labor[1]			
Auditing, hours	980	$45,001	
Support, hours	55	$ 2,519	
Reporting, hours	55	$ 2,519	
Training, hours	210	$ 9,178	
			$59,696
Real-time notification machine learning system			
Labor[1]			
Support and maintenance	418	$19,177	
Material costs[2]			
Annual patient load	228,716		
Patient turnover	3 patients /(hour & room)		
Annual availability per room	2,088 hours		
Notification systems necessary	37	$12,612	
			$31,790

1: Costs per hour of labour = $45.92; 2: Costs per system = $340.89

Figure 1: Prototype development and study timeline

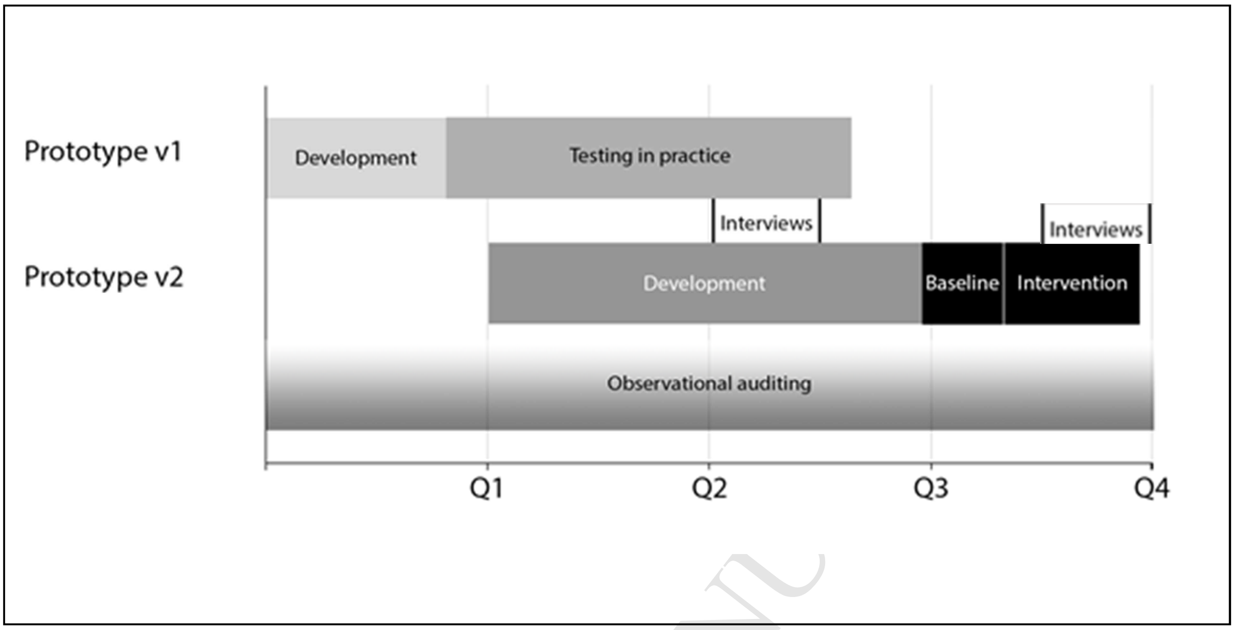
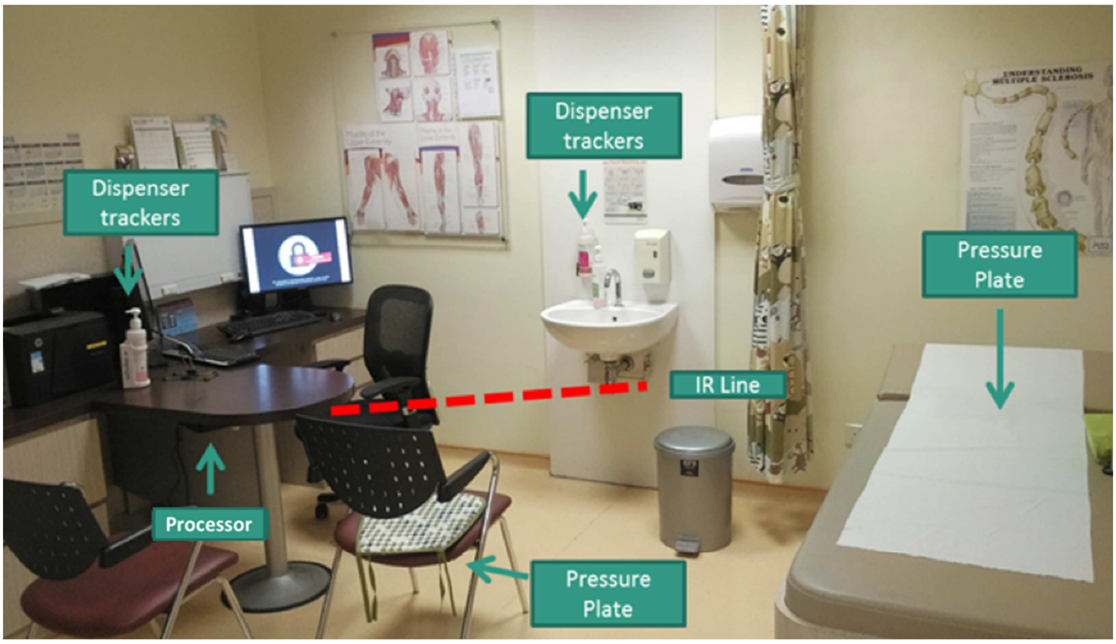


Figure 2: Setup of the real-time hand hygiene notification machine learning system



Supplement 1 Template for stakeholder interviews

Respondent:

Function:

Date:

Time:

Location:

Thank you for participating in this interview.

1. What is your general opinion on the relevance of HH and HAI in outpatient setting?

2. What are the main barriers for not performing HH in outpatient setting?

3. What is your perception of the currently tested infrared/sensor prototype?

4. What is your experience on the current auditing practice and its effects?

5. How important is a focus on real-time reminding?

6. What are the biggest hurdles in implementation of the current prototype?

7. Are there any other (general) related issues that need to be addressed?

Thank you.