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To Investigate the Validity and Reliability of a Radio Frequency ID/Electronic Exciter System in Detection of Hand Washing Events; and to Investigate Nurses' Hand Hygiene Practices and Explore the Social and Behavioral Factors which Influence these Practices

Kaunda, Joseph Josaphat

UNIVERSITY OF CALGARY

To Investigate the Validity and Reliability of a Radio Frequency ID/Electronic Exciter System in Detection of Hand Washing Events; and to Investigate Nurses' Hand Hygiene Practices and Explore the Social and Behavioral Factors which Influence these Practices

by

Joseph Josaphat Kaunda

A THESIS

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ABSTRACT

Background: HH is the most important strategy to prevent spread of hospital-acquired infections. HCWs' HH compliance is typically 30-50%. Human monitoring of HH is inconvenient and labor-intensive.

Purpose: Objectives. Sub-study 1: Investigate validity and reliability of an RFID system in detection of handwashing events. Sub-study 2: Investigate changes in HH compliance and duration with perceived level of infectious risk (PRF). Sub-study 3: Explore social/behavioral factors which influence HH practice.

Design: Observational.

Results: RFID system *Sensitivity* =0.175[0.057, 0.293]; *PPV* =0.778[0.649, 0.907]; *Reliability* =0.266[0.109, 0.520]. HH compliance was higher for higher PRFs, χ-square =67.36, $p<0.0001$. Handwashing duration was longer for higher PRFs, χ-square =18.25, $p<0.0001$. *Meaning* of Hand Hygiene is central to nurses' HH practice.

Conclusion: RFID system has poor reliability but reasonable validity when used for detecting handwashing. HH compliance is higher and handwashing duration longer after exposure to higher PRFs. Meaning of HH is central to HH practice.

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CHAPTER ONE

INTRODUCTION AND PURPOSE

1.1 Introduction

Since 1847, when Hungarian physician Ignaz Semmelweis demonstrated the association between hand hygiene and hospital-acquired infections, hand hygiene has been known to be the single most important strategy in preventing the spread of hospital-acquired infections (HAIs) (1-3). The growing financial, economic and social burden that these infections lay on healthcare systems, society and individuals suggests that these infections warrant closer attention than they have been receiving. On average, each HAI is estimated to cost $14,000 in direct costs to the healthcare system (4, 5). The World Health Organization, WHO, estimates that at any moment, there are 1.4 million people affected by healthcare-acquired infections among hospitalized patients around the world (6). In the United States, 250,000 episodes of hospital-acquired blood stream infections are reported annually. Thirty five percent of patients with HAIs die from their infections. Among survivors, each spends an average of 24 additional hospital days, which costs an additional $40,000 per individual (2). And this is only the direct financial component of the cost. Other cost components, such as morbidity and sequelae and their associated decline in quality of life as well as loss of income are also quite significant (7).

The situation here in Canada is not any better. Between 220,000 and 250,000 cases of HAIs are reported annually. Up to 12,000 deaths are directly attributable to these infections annually. Hospital-acquired infections rank as the fourth largest killer in the country (8). Studies show that up to 30% of all HAIs are preventable (9, 10). Thus, based on the average cost of $14,000

per infection, the annual number of HAIs in the country and this preventable percentage, the struggling Canadian healthcare system could save up to $1 billion annually if better strategies for prevention and control of HAIs are employed. Hand hygiene is the best strategy for prevention of spread of HAIs (1-5). Therefore, stricter adherence to hand hygiene practice by healthcare workers (HCWs) could have significant impact on rates of HAIs. Indeed studies have shown correlation between improved hand hygiene compliance and reduction in healthcare-acquired infections (11, 12).

1.2 Research Rationale

Despite these statistics, hand hygiene compliance by HCWs has persistently been less than satisfactory, typically hovering in the 30-50% range, often lower (3, 13-16). However, hand hygiene (HH) compliance, which is defined as the number of times hand hygiene is performed compared with the number of hand hygiene opportunities, is only one piece of the hand hygiene puzzle. If all other factors such as quality of the practice and appropriateness of the method are taken into account, the rates of proper and effective hand hygiene drop even further. Therefore issues around hand hygiene are much more complex than is apparent. Thus, hand hygiene practice can have significant impact on patient outcomes as well as on the overall cost of healthcare. Understanding the practice of hand hygiene as well as factors which influence it is necessary for implementation of interventions which will improve the practice. In addition, technology plays an increasingly important and prominent role in healthcare, just as with other aspects of modern life. This includes application in the practice of hand hygiene (17-27). But the effectiveness and appropriateness of these technologies need to be verified (19, 22, 23, 25). This study investigated the validity and reliability of an emerging hand hygiene

measurement technology as well as hand hygiene practice and factors which influence the practice.

1.3 Research Purpose and Specific Aims

The purpose of this study was to explore various aspects of hand hygiene practice in an applied healthcare setting. These include determining the validity and reliability of Radio Frequency Identification (RFID) Wi-Fi technology in detecting hand washing events; investigating determinants of hand hygiene practice and exploring social and behavioral aspects of hand hygiene practice in the healthcare setting.

1.4 Research Questions

The study consisted of three related sub-studies. Sub-study 1 aimed at answering the question: Is a Wi-Fi, Radio Frequency ID/Exciter (RFID) system a valid and reliable tool for detection of hand washing events in the healthcare setting?

Sub-study 2 aimed to answer two research questions. The first question was to investigate whether hand hygiene compliance by nurses in the healthcare setting increases with perceived level of infectious risk associated with the nurse-patient interaction. The second question was to investigate if nurses' hand hygiene duration increases with perceived level of infectious risk associated with the nurse-patient interaction.

Two null hypotheses were generated from these two research questions for sub-study 2. Null Hypothesis 1, H_{o1}, for the first research question stated that nurses' hand hygiene compliance is not higher for perceived high infectious risk associated with the nurse-patient interaction than for perceived low infectious risk. The null hypothesis for the second question, H_{o2}, stated that

nurses' hand hygiene duration is not longer for perceived high infectious risk associated with the nurse-patient interaction than for perceived low infectious risk.

These two sub-studies were quantitative in nature and were therefore conducted using deductive techniques. Sub-study 1 involved taking measurement to determine the validity and reliability of an RFID/Exciter system when used as a tool for detection of hand washing events. This determination was performed using deductive approach. Sub-study 2 involved hypotheses testing, which is a common approach in deductive inquiry. This type of inquiry commences from a hypothetical, unconfirmed position then proceeds to verify and confirm or reject the hypothesis.

The objective of sub-study 3 was to answer the question: What social and behavioral factors influence nurses' hand hygiene practice? Findings from this sub-study were then to be used to explain observations in sub-study 2.

Sub-study 3 involved inductive exploration to identify relationships and factors which influence hand hygiene practice and underscore the challenges and complexity of measuring hand hygiene. Data collected from interviews were analyzed and theory generated to help explain and understand hand hygiene results that had been observed in sub-studies 1 and 2. This commencement from data to theory is a feature of inductive inquiry.

Sub-study 3 is important because in most interventional hand hygiene studies, success is determined based on measurement of hand hygiene practices (28). But this measurement is imprecise. It is important that our understanding and assumptions about behavior align with our outcome measures.

CHAPTER TWO

REVIEW OF THE LITERATURE

2.1 Introduction

This literature review gives the results of an electronic search for the relevant literature on work done in relation to hand hygiene in the healthcare setting. The search was done primarily from CINAHL and Medline databases. The specific areas of interest included hand hygiene, measurement of hand hygiene compliance, hand hygiene quality and hand hygiene technique. Also searched were use of technology in hand hygiene monitoring and measurement, barriers to hand hygiene performance and social and behavioral factors associated with performance of hand hygiene.

2.2 The Hand Hygiene Process

Performance of an effective hand hygiene act by a healthcare worker in the healthcare setting is a much more complex undertaking than is generally apparent. The components of this process can be divided into two broad categories: hand hygiene methods and hand hygiene techniques.

2.2.1 Hand Hygiene Methods

To perform hand hygiene, the healthcare worker can opt for any one of three methods. The healthcare worker could opt to wash hands with soap and running water or use of alcohol hand-rub. Some healthcare workers may prefer to use both, that is, one method followed by the other, for the same hand hygiene opportunity.

Washing hands with soap and water is the traditional method for hand hygiene. This involves using liquid soap from a dispenser and warm, running water. Plain soap is used for most

applications. However, antimicrobial soap is used in specialized environments such as for surgical applications. To help prevent spread of water-borne organisms, it is recommended that hand washing in the healthcare setting be performed at sinks that are dedicated for hand washing purposes (3, 4). There are situations in the hospital where hand washing with soap and water is the indicated method of hand sanitization. The two most common situations for which hands must be washed are when hands are visibly soiled or after exposure to spore-forming micro-organisms such as *Clostridium difficile* bacteria as well as norovirus (29, 30).

In many hospitals, most patient-care areas are stocked with regular soap that does not have any anti-microbial properties. Therefore washing hands in these areas does not kill micro-organisms. Rather, it is the friction due to rubbing of hands and the emulsifying properties of soap which loosen the micro-organisms and dirt and wash them down the drain (29). A proper and effective hand wash therefore should take into account a number of elements. These elements considered together constitute hand washing technique.

2.2.2 Hand Washing Technique

The purpose of washing hands is to clean them of dirt and microbial contaminants. How the hands are washed is therefore an important component of the hand hygiene process. Systematic evaluation of hand washing technique was first performed by Feldman using what came to be referred to as Feldman's criteria (14, 16, 31-34). These criteria were based on nine elements of the hand washing act which Feldman considered important for effectiveness. The central criterion was that liquid soap and clean running water had to be used. During the hand washing process, hands were supposed to be positioned in such a way that they would not be re-contaminated. Feldman also considered it important to avoid splashing on clothing or floor.

Vigorous friction on hands applied on all surfaces was to be followed by thorough rinsing. During rinsing, hands were to be held pointing downwards. Finally hands were to be dried thoroughly and the faucet turned off with a paper towel.

Gould (35) pointed out that at the time Feldman launched his criteria, hand washing was the only method of hand sanitization used in the healthcare setting. The introduction of alcohol hand-rub as an alternative and preferred method for hand sanitization meant that progressively fewer situations would require hand washing, and thus relevance of Feldman's criteria. If the healthcare worker opts to use alcohol hand-rub instead of washing hands, these criteria would be rendered irrelevant. In addition, a healthcare worker could use alcohol hand-rub in a situation where hand washing is the indicated hand hygiene method. This scenario would further complicate evaluation of hand washing technique.

Therefore, while Feldman's criteria are still useful in the increasingly rare patient-care environments where hand hygiene is restricted to hand washing only, the recommendation that most hand hygiene events be performed using alcohol hand-rub (30, 36-39) diminishes the prominence of Feldman's criteria and other measurements for the hand washing technique.

Questions have been raised about the scientific evidence supporting some of Feldman's criteria. In her study exploring the effectiveness of the hand wash with hands in different positions, Conroy (40) found no difference in residual microbial counts with hands washed in the up, down or lateral positions. This finding is contradictory to expectations from Feldman's criteria.

Other measurement methods and scales for hand washing technique and quality have been used with varying degrees of success. One such scale is the Fulkerson Scale, which was

introduced in the 1970s. The scale lists 15 typical healthcare activities and ranks them according to increasing perceived risk for hand contamination (16). Fulkerson classified activity number 1, that is, contact with sterile equipment, as the cleanest, while number 15, that is contact with infected wounds, was ranked dirtiest. The first seven items were considered clean, but were graded as progressively dirtier with increasing number on the scale. Activities numbers 8 to 15 were rated from dirty to dirtiest. Thus, Fulkerson's scale was an intermediate tool incorporating both elements of hand washing quality and hand washing opportunity.

In her study using Fulkerson's scale to determine whether hand washing should have been performed in different situations, Taylor (41) found that in 129 observations, nurses did not distinguish between clean and dirty situations. Reproducibility of the study was not recorded, and therefore the validity of the results cannot be ascertained. In another study, Wendt et al. (42) conducted observations on a variety of patient-care units to investigate hand hygiene compliance for the different elements of Fulkerson's scale. Their results show that compliance did not follow the scaling. Overall hand hygiene compliance was observed to be 52%. While compliance after contact with fecal matter was 90% - 97%, compliance after contact with sterile supplies, that is, the cleanest element on the scale was a surprisingly high 32%. This was much higher than the lowest observed rate of 12% for contact with materials and equipment which had not come into contact with the patient. The weakness of this scale is that it is based on perception. There is no evidence in the literature that the scale is supported by scientific backing.

Attempts have been made to address some of the deficiencies which were identified in Feldman's criteria. Larson et al. (16) integrated elements from Fulkerson's scale into Feldman's

criteria. The result was weighted criteria with a point system based on perceived importance of each element of the criteria. Duration of the hand washing activity was also introduced as an additional element. From their tests, they concluded that the tool was reproducible in different settings and it was therefore considered a significant improvement on Feldman's criteria.

A different approach to evaluating hand washing technique was taken by Ayliffe et al. (43, 44). They considered Feldman's criteria to have too many deficiencies and thus rejected them. Instead, they proposed an eight-step method for evaluation of hand washing effectiveness. Using their approach, the healthcare worker is supposed to wet hands with clean, running water and apply soap on all surfaces of the hands. Alternate palms are to be rubbed with interlocking fingers. Thumbs are to be rubbed using rotational motion on the palms. Finally both wrists are to be thoroughly rubbed followed by rinsing.

However, there is a lack of evidence in the literature showing that any specific step in Ayliffe's approach had an effect on the effectiveness of the hand wash. Like the Fulkerson scale, these steps were based on perception. Further changes to Feldman's criteria were introduced by Gould (33). Gould also rejected Feldman's criteria because of lack of evidence that bacteria from splashing during a hand washing event ever caused infections. Instead, she proposed and used a new set of criteria with four points. As was the case with Larson, Gould also considered the duration of a hand wash to be important, and thus included it as one of the points. Gould's four points were thoroughness of hand coverage, duration of the hand washing act, drying of hands and re-contamination. As with the other approaches and modifications to Feldman's criteria, Gould's four steps also lacked scientific backing.

From the literature search, it was evident that there is a dearth of published work on hand washing quality and technique; and that most of what has been done was done in the 1970s to early 1990s. While there are significant methodological inconsistencies in the different approaches to evaluating hand washing technique, there is also lack of published evidence that work is currently being done in this area. Is hand washing technique therefore an exhausted field for study, or has hand washing technique become irrelevant? Or, is researching hand washing technique too complex an undertaking, especially considering that the potential effects of many of the variables lacks scientific support in the literature?

2.2.3 Alcohol Hand-Rub

The introduction of alcohol hand-rub as a hand hygiene agent brought a big shift in how hand hygiene is performed in the healthcare setting. With greater emphasis being laid on use of alcohol hand-rub over hand washing, the hand-rub is now considered the primary method for hand sanitization (15, 29, 30, 36, 39).

One of the main advantages that alcohol hand-rub has over soap and water is that unlike the latter, alcohol kills the microorganism. In her systematic literature review on the effectiveness of alcohol hand-rub, Picheansathian (45) came to the conclusion that when used correctly and at the correct concentration of 60-90% alcohol content, the hand-rub practically eliminates all bacterial colony-forming units on the hand. Alcohol hand-rub has the added advantage of being fast, convenient to use, easily available and more economical than soap and water (45, 46). In addition, despite the widely-held belief by many healthcare workers that alcohol hand-rub dries hands (47), modern formulations, which include emollients, have been shown to be much gentler on hands than the friction of hand washing. Boyce et al. (30) found that skin irritation

and dryness of hands increased significantly when nurses washed hands with regular soap in comparison with when they used alcohol hand-rub (48). Similarly, Girard et al. (49) found improved skin tolerance and hydration with alcohol hand-rub than with hand washing. Loffler et al. (50) and Winnefeld et al. (51) also arrived at the same conclusion. In their questionnaire study on nurses' perceptions on hand washing vs. alcohol hand-rub, Stutz et al. (47) also arrived at the same conclusion. An additional finding was nurses' perception that alcohol hand-rub was more damaging to the skin than hand washing. This was found to lead to lower compliance with alcohol hand-rub and preferentially more hand washing; a vicious cycle which led to even more dermatitis (36, 47).

2.2.4 Hand Hygiene Technique using Alcohol Hand-Rub

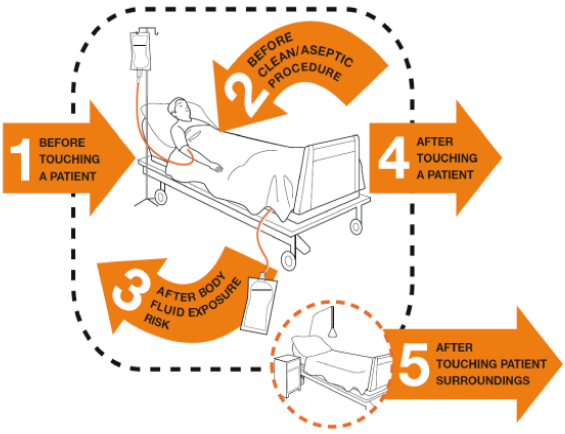
Unlike hand washing which has a number of varying and even contradictory criteria for judging effectiveness of technique, alcohol hand-rub has one set of simple guidelines: Dispense approximately 3ml of product on hands that are not visibly soiled, then rub vigorously covering all surfaces until dry (35, 52). Tvedt et al. (53) showed that because these instructions are simple and easy to use effectively, alcohol hand-rub is less susceptible to technique problems than hand washing. Findings by Hautemaniere et al. (54) agree with this conclusion but point out that the presence of rings, long nails and watches are factors which are associated with poor hand hygiene technique when alcohol hand-rub is used. While the overall guideline for use of alcohol hand-rub is simple, minor variations in technique, such as specifying duration for rubbing hands together, do exist (46). In addition, variation in alcohol hand-rub consistency, that is, foam, liquid or gel, as well as differences in atmospheric temperature and humidity,

hand sizes and the fact that users take different amounts per event make the time duration in the general guideline questionable.

2.3 Hand Hygiene Compliance

In the healthcare setting, the ultimate objective for performing hand hygiene is to prevent spread of hospital acquired infections (1-5, 55, 56). How hand hygiene is performed is therefore an important component of the hand hygiene process (1-5, 55, 56). Hand hygiene compliance refers to the performance of hand hygiene when it is required to be performed. The World Health Organization, WHO, summarized all these moments when hand hygiene is required to be performed into five moments. These are referred to as *My Five Moments for Hand Hygiene* (57). Moment 1 is performance of hand hygiene before contact with patient or patient environment. Requirement to perform hand hygiene before a clean or aseptic procedure is the second moment. After a healthcare worker has been potentially exposed to body fluids, hand hygiene is expected to be performed. This is the third moment. After contact with the patient or patient's environment constitute the fourth and fifth moments respectively. An illustration of these five moments is shown in Figure 2.1. While the goal of the five moments of hand hygiene is to provide a practical tool for teaching and promoting healthcare worker hand hygiene compliance (58) this definition is limited as it does not include random or non-patient care-related hand hygiene activities, such as before meals or after bathroom visits.

Figure 2.1: World Health Organization's My Five Moments for Hand Hygiene



Of note, in Canada, the common practice is to combine Moments 4 and 5 into one moment in an attempt to improve healthcare worker compliance by reducing the number of moments; thus four moments is promoted, rather than the five moment approach, which is used everywhere else around the world.

In contrast with studies on hand hygiene technique, there are many studies on hand hygiene compliance still being conducted and published in the literature. A number of unresolved issues drive the need for these studies. Chief among these is the fact that hand hygiene compliance numbers remain stubbornly low despite multiple and varied interventions over the years (29, 30). Also, unlike hand hygiene technique, hand hygiene compliance is independent of the method used, whether hand washing or use of alcohol hand-rub. Compliance does not take into account the complexities of technique, quality or effectiveness of the hand hygiene act. It only focuses on whether or not the act was performed when required (57). In addition, unlike technique, compliance is a much more straightforward and easily measurable concept, and therefore designing compliance studies is much easier and more direct. The emergence of technologies for measuring hand hygiene and the growing need for efficient and accurate, yet

non-labor-intensive measurement methods also continue to spawn studies on hand hygiene compliance. By comparison, measurement and evaluation of hand hygiene technique often involves too many variables, including complex environmental, social and behavioral considerations.

2.4 Measurement of Hand Hygiene Compliance

Four methods are most commonly used for measuring hand hygiene compliance. These are direct observation, electronic monitoring, self-reporting and monitoring product usage.

2.4.1 Direct Observation

Direct observation is considered the gold standard for measurement of hand hygiene compliance (30, 57, 59-61). In this method, the trained observer observes and records the actual hand hygiene practice without going through proxy variables. This observation is done in real time. The method has the advantage that the observer can see and record any unusual events which might impact the participant's normal hand hygiene practice. Such events would include emergencies, where recommended hand hygiene practice becomes secondary to the immediate life-saving demands of the situation. Thus, by this method and based on observer accuracy, what is recorded is what actually happened.

Sax et al. (57) gave step-by-step guidelines on how to use direct observation with the five hand hygiene moments template. Whenever one such moment presents itself, the trained observer records it as a hand hygiene opportunity. If the healthcare worker performs hand hygiene for that opportunity, it is recorded as an opportunity utilized, or not utilized if it was missed. The number of all utilized opportunities divided by all opportunities observed is the hand hygiene compliance rate.

A key advantage that direct observation has over other methods is that by this method, it is possible to calculate individual compliance rates for each of the five moments. Hand hygiene compliance for different categories of healthcare workers and even differences between hand washing rates and those for use of alcohol hand-rub can be determined. Among the four methods, direct observation also has the advantage of being the only one which can assess hand hygiene technique or quality of the practice.

Despite these advantages, direct observation also has some significant disadvantages. This method is very labor-intensive and therefore can be quite costly. For a one-time study, this disadvantage may not be a serious problem. However, in the practice of infection control in the healthcare setting, many programs employ continuous or repeated cycles of observation, intervention then observation again before repeating the cycle (57, 60). In these cases, the cost from the heavy use of labor has to be taken into consideration. In an attempt to offset this labor-intensive aspect of direct observation, newer techniques have recently been introduced. Internet-capable programs applications such as *iScrub Lite* make recording and analysis of data much faster, cheaper and easier (17).

By direct observation, data collection is often performed by a variety of observers. These range from infection control professionals to nurses, physicians, volunteers and students. Although data collectors are generally often trained for the job, they have such varied professional backgrounds that it is not certain that they would classify similar events the same way (30). Another significant challenge facing researchers using direct observation is how to collect data without affecting the participant's natural hand hygiene practice. Ethical considerations require that those being observed or studied should give informed consent. But full disclosure is likely

to lead to behavior modification by Hawthorne Effect. Several techniques, such as using local staff members as observers and other covert techniques may be considered. However, Sax et al. (57) caution against covert observation. While covert observation only temporarily resolves the Hawthorne issue, it introduces new challenges. An observer who is a staff member is no longer a neutral player. This then becomes a potential source of bias. In addition to ethical concerns associated with covert observation, Sax et al. (57) also emphasize the unreliability and the irreproducible nature of these approaches. They point out that Hawthorne effect can, however be used as a tool for improving hand hygiene compliance.

Cameras may be installed in strategic locations as a strategy to address the labor-intensive disadvantage of direct observation. However, cameras have limited view, and therefore may introduce a form of selection bias (17, 57). Other disadvantages for camera use include the great expense required to install sufficient numbers of cameras and the sizeable labor that will be needed to process the large amounts of data collected by the cameras. Use of cameras may also introduce new ethical issues such as the need for consent to be observed by camera.

An additional challenge for direct observation methods is the fact that variables are often defined differently for the different study designs (61). Some study designs are based on observation of hand hygiene throughout the entire patient encounter while others randomly observe opportunities as they present themselves in the patient-care environment. Comparing findings from the two could lead to erroneous conclusions.

In their observational study on hand hygiene compliance, van de Mortel et al. (18) concluded that direct observation only sees approximately 0.4% of all hand hygiene opportunities on a nursing floor. Questions can then be raised if this sample is sufficient and representative

enough for the findings to be valid and to justify generalizing to the entire unit and beyond. This is especially so considering that observations are typically made over a period of an hour or two at a time, and mainly during day shifts only. Thus, shift-based selection bias is a concern. Also, variations between individuals are not taken into account during observation.

In making a comparison between random observations on the unit and monitoring the entire patient encounter series, Eveillard et al. (31) concluded that it is more beneficial to the patient to look at the complete encounter with a healthcare worker, rather than convenient observation of single, isolated and unrelated episodes around the unit. However, the approach of monitoring the entire encounter also has challenges such as what to do when personal care is given behind closed doors or drawn curtains.

Thus, while direct observation is generally considered the most reliable method for hand hygiene monitoring, it has significant drawbacks that should be taken into consideration when designing studies using the method.

2.4.2 Electronic Monitoring

Apart from observation cameras, other electronic methods can also be used for monitoring hand hygiene compliance. Electronic monitoring uses different variables as surrogates for hand hygiene performance. The most common approach is to record entry or exit from a patient room or zone as a hand hygiene opportunity. In this arrangement, sinks and alcohol hand-rub stations are pre-wired with electronic detectors. If none of these detectors is triggered shortly after entry or at exit from patient room, this is recorded as a missed opportunity. But this design often requires that the healthcare worker wears an electronic tag. Ethical issues and user response to wearing a monitoring tag therefore need to be addressed when using this

method. The great advantage of electronic monitoring is that it can continuously monitor hand hygiene without interfering with patient care.

Designs generally fall into two broad categories: Dedicated hand hygiene monitoring systems and Real Time Locating Systems (RTLS) (17). In dedicated designs, technologies that are specifically designed for hand hygiene monitoring are used. Swoboda et al. (19) used a dedicated monitoring system consisting of motion sensors and integrated voice prompts to alert the healthcare worker when an opportunity was missed. They recorded a decrease of up to 48% in hospital-acquired infections during the study period and beyond. Vankatesh et al. (20) used a similar approach and recorded a hand hygiene compliance rate increase from 36% to 70%. Sahud et al. (21) also undertook a study to validate findings from a dedicated electronic system against direct observation. Direct observation showed a compliance rate of 32% compared with 25% for electronic monitoring. They concluded that because electronic monitoring recorded many more events, findings from this method may be more reliable than those from direct observation. Other researchers have also conducted similar studies based on room entry and exit as proxy hand hygiene moments. Cheng et al. (22) used a *MedSense* electronic monitoring system in a three-month trial to evaluate performance of the system. They concluded that the system is unobtrusive and less susceptible to Hawthorne Effect, yet has a performance that is comparable to direct observation. However, it must be noted that in Cheng's study, the observer recorded all the five moments, whereas the electronic system was limited to only room entry and exit. Thus, whereas measurement of compliance at room entry and exit was a good surrogate for true compliance, compliance after important exposure events, such as exposure to body fluids, would potentially have been missed.

Cost-effective dedicated systems have also been tested. Polgreen et al. (23) installed a network of simple programmable transmitting beacons inside and outside patient rooms as well as at hand hygiene stations. With fine adjustment, the system was able to record most room entry and exit events as well as their associated hand hygiene opportunities and compliance. The researchers concluded that this was an effective and inexpensive way to monitor hand hygiene compliance. A different variation was tested by Granado-Villar et al. (24). They conducted an interventional study using infrared and acoustic sensors to monitor hand hygiene compliance, and intervene as necessary. In their study, they installed wall-mounted sensors to create an infrared and acoustic zone around a patient's bed. The sensors were programmed to detect the presence of a special electronic badge that was worn by healthcare workers. If the badge-wearing healthcare worker entered the infrared/acoustic zone, that would register as a hand hygiene opportunity. When the healthcare worker would then pass a hand under a different sensor, the sensor would detect residual soap or alcohol and give him a pass for compliance. If the test failed or was not done, the badge would vibrate reminding the worker to perform hand hygiene. The system recorded overall hand hygiene compliance of 94%.

Real Time Locating Systems (RTLS) is the other category of electronic monitoring. RTLS is a versatile technology which can be used for a variety of applications. These include keeping track of equipment, tracking patients, establishing workflow patterns and nurse call events among others (17). The system can also be configured to monitor hand hygiene activities. When the system is used for hand hygiene applications, the healthcare worker wears a special badge with wireless communication capabilities. The badge can communicate with sensors mounted at different locations in the facility. Interaction between a badge and a sensor that is mounted at a

hand hygiene station is recorded as a hand hygiene event. Calculating these events against room entry and exit data gives the hand hygiene compliance rate.

Electronic monitoring also has significant shortcomings. In their literature review on auditing hand hygiene methods, Gould et al. (25) identified some of these deficiencies. Surrogate variables never match 100% with what they are supposed to represent. For example, entry into a patient room or getting within the patient zone does not necessarily mean that contact with the patient or his environment was established. Moreover, this method cannot account for what may have transpired between entry into the room and leaving the room. By this method, it is therefore not possible to tell whether there were multiple exposures to body fluids during the nurse-patient interaction or whether sterile procedures were involved. It is also not possible to link any hand hygiene recorded with its corresponding hand hygiene opportunity. The quality of any hand hygiene performed would also be unknown.

In a study to determine hand hygiene station location preferences, Boyce et al. (26) found that healthcare workers used hand hygiene stations located in the corridors more often than those in patient's rooms. As this reality would be missed under electronic monitoring, compliance at a corridor station before room entry or after room exit, which would be expected to be many, would be misclassified as missed opportunities. Also, most electronic monitoring systems require that participants wear electronic tags. While this may be acceptable during the study period because informed consent is given, ethical implications beyond this period are still unclear. To investigate this, Boscart et al. (27) conducted a descriptive study to assess the acceptability of wearing such a tag. All ten staff in the study found it acceptable to wear the

badge-sized electronic monitoring tag. However, whether this can be generalized to other settings is unknown.

Thus, electronic methods tend to concentrate on Moments 1 and 4/5, that is, before entry into patient room/zone and after being in the patient environment. The key, high risk moments such as before aseptic procedure or after exposure to body fluids are not taken into consideration. Results and conclusions from this method can therefore be misleading. Other types of electronic studies are interventional and are discussed under interventional studies.

2.4.3 Self-Reporting

Self–reporting is the easiest and most cost-effective method to measure hand hygiene compliance (29, 62, 63). In this approach the healthcare worker reports his or her own hand hygiene compliance and technique. However, as can be expected, anyone can report anything; which can be difficult to validate. Standard control measures such as minimizing bias, sample size and randomized selection process are all missing in this method. A comparison of findings from this method with direct observation shows that most healthcare workers over-report their own compliance rates (29, 62-64). O'Boyle et al. (65) found that nurses over-reported their compliance by as much as three times. Findings from this method are thus of questionable validity.

2.4.4 Product Usage Monitoring

Monitoring product usage is a cost-effective method of monitoring hand hygiene. This monitoring can range from manual or electronic tracking of soap or alcohol hand-rub volumes usage per patient days in hospital to more complex dispenser-based counts (59). By this method, the recommended volume of product per use is considered one hand hygiene event.

Approximately 3ml of liquid soap or alcohol hand-rub is the amount generally considered to represent one hand hygiene event (35). Compliance rates are then calculated based on expected hand hygiene opportunities for a generic patient-care unit similar to the one under study. Alternatively, comparison can be made with direct observation.

Although this method is economical and easy to apply, like the others, it also has drawbacks. All hand hygiene product use on a nursing floor is assumed to be patient-care related. Visitor usage, spills, different volumes per individual etc. are not controlled for. Despite the method having these shortcomings, van de Mortel (18) argued that because of the extremely small percentage of observed hand hygiene opportunities during direct observation, that is, 0.4%, as compared to all opportunities that arise, measuring product usage across the entire unit or hospital may be a more valid method than direct observation.

As is the case with electronic monitoring, product usage monitoring also suffers the drawback of the researcher not being able to identify specific practice weaknesses of healthcare workers such as poor technique. The method is also unable to link the hand hygiene event with its corresponding opportunity; or to break down hand hygiene compliance by healthcare group categories etc. Moreover, although some studies have shown improved compliance with product usage (52, 66-68), others have found no correlation between the two (18, 69). This suggests that increased product usage does not necessarily imply improved hand hygiene performance or compliance. By definition, hand hygiene compliance is based on hand hygiene opportunities around patient care. Measuring product use has no way of assessing hand hygiene opportunities, and therefore relies on generic estimates or direct observation as a reference (67).

2.5 Barriers to Hand Hygiene Performance

Despite the serious consequences on patient outcomes and the high cost associated (2, 4, 5) with healthcare-acquired infections (7, 9-12), as well as the importance of hand hygiene in lowering the number of these infections, hand hygiene compliance has remained low (3, 13-16, 29, 30). Why do healthcare workers maintain such low numbers for such an important metric of healthcare quality and patient outcomes? What are the barriers to performance of hand hygiene? In an attempt to answer these questions, McGuckin et al. (70) interviewed medical, nursing and infection control staff in an acute-care Intensive-Care Unit. Lack of access to sinks, lack of time and being busy were stated as barriers to hand hygiene compliance. Some healthcare workers also listed insufficient personal accountability and different attitudes towards hand hygiene as reasons. Also listed were high costs of product and hand hygiene initiatives, as well as claims of drying and cracking hands. This claim was especially made in relation to use of alcohol hand-rub.

Since it was introduced in healthcare as a hand sanitizing agent, alcohol hand-rub has been promoted as the primary method for hand sanitization in the healthcare setting (57). It is therefore of interest that healthcare workers associate its use with drying and cracking of hands (71-73). Boyce et al. (48) and Picheansathian (45) already showed that the opposite is true.

2.6 Interventional Studies

The bulk of studies in hand hygiene have been interventional in nature, aimed at improving hand hygiene compliance (28). This is not surprising considering the persistently low compliance numbers. Based on barriers identified by healthcare workers, interventional studies have naturally been tailored to address one or different combinations of these barriers.

In general, evidence in the literature shows that bundled interventions, incorporating more than one interventional element, have been more successful than single-element interventions (15, 29). In an observational study to investigate the effect of feedback, education and surveillance on hand hygiene compliance, Benton et al. (74) concluded that this combination resulted in increasing compliance among physicians. Applying the different combination of education, feedback and provision of alcohol hand-rub at the bedside, Creedon et al. (75) observed an increase in hand hygiene compliance from 51% to 83%. Similarly, Pittet et al. (15) concluded that hand hygiene compliance may improve through a multi-modal hospital-wide approach involving communication, education and feedback. Using other different combinations, other researchers have come to a similar conclusion. The interventional study by Swoboda et al. (19) using a combination of electronic monitoring and voice prompts recorded an increase in hand hygiene compliance as well as decrease in hospital-acquired infections.

By comparison, a review of single-strategy interventions shows much fewer cases of success. In their systematic literature review investigating success of different hand hygiene interventional strategies, Naikoba et al. (76) similarly concluded that multi-intervention strategies had higher and more sustained success rates than single-intervention approaches. McGuckin et al. (70) had reported lack of availability of sinks as a stated barrier to hand hygiene compliance. However, when Lankford et al. (77) conducted an assessment on the impact of increased numbers and accessibility of hand hygiene sinks in a newly-built hospital in comparison to the arrangement in an older hospital, their findings were contrary to expectation. This installation of sinks was a single-element interventional strategy aimed at addressing a specific stated barrier to hand hygiene performance. Their findings show that this intervention did not lead to improved hand

hygiene compliance. On the contrary, compliance decreased substantially. However, they found that compliance by a peer or higher ranking person led to increased compliance.

The effect of hand hygiene feedback to the healthcare worker as a single-element intervention was investigated by Marra et al. (78). Results show that this intervention had no effect on hand hygiene compliance. However, there were some cases of successful single-element interventions. In their study with electronic monitoring, Vankatesh et al. (20) concluded that electronic alerts reminding healthcare workers when to perform hand hygiene were effective in improving hand hygiene compliance.

As different combinations of interventions have been shown to be relatively effective in comparison to single-strategy interventions, the challenge that remains unresolved is to identify the specific element in the combination which may have led to the improved compliance.

2.7 Hand Hygiene Practice

As mentioned earlier, an advantage of the direct observation method is that using the method, hand hygiene compliance can be broken down to the individual hand hygiene moments of the *My Five Moments* structure (Figure 2.1). How have healthcare workers performed in these individual moments?

Findings show that hand hygiene compliance is higher after patient contact than before patient contact (52, 64, 78-82). In the study by Lankford et al. (77) for example, hand hygiene compliance was found to be higher after patient contact, after removal of gloves and after performing an invasive procedure. Compliance before patient contact was found to be significantly poorer than after contact. They theorized that hand hygiene practice by healthcare

workers may be driven by perceived risk to themselves, and not to the patient. Finally, because hand hygiene compliance was found to be higher after glove use than before, they concluded that, glove use may be used as a marker for hand hygiene compliance. This conclusion was based on the premise that healthcare workers wear gloves for self-protection, and that they perform hand hygiene better after patient contact than before patient contact.

In a study comparing direct observation with product use monitoring in three intensive care units including an NICU, Scheithauer et al. (52) found that hand hygiene compliance rates were low in situations with the highest risk for transmission of infection to the patient. Compliance before an aseptic procedure was observed to be 23% in one ICU. To account for any variations across shift lines, Scheithauer's (52) observations ran around the clock. No significant practice variations across shift lines were noted. Similar results were found by Wendt et al. (42). In their study, they observed compliance rates of 51% in ICUs and 72% on regular medical/surgical units respectively. They attributed the lower compliance rate in the ICU to higher work pressure.

Other components of an effective hand wash have also been found to fall below recommended levels. The recommended duration of an effective hand wash ranges between 15 seconds and 1 minute in various guidelines (16, 29, 30, 33, 57). Fox et al. (34) found that in practice, the duration fell far below these recommendations.

2.8 Effect of Gloves

During the course of patient-care, situations often arise for which glove use is indicated. These instances include performance of aseptic procedures and potential exposure to blood and other body fluids. Sax et al. (57) in World Health Organization hand hygiene guidelines point out that use of gloves is not a substitute for hand hygiene. Gloves are only meant to protect from gross

contamination, but they do not give total protection. This is because the glove material is a thin, semi-permeable membrane which cannot guarantee perfect protection. Moreover, donning and doffing techniques are not always perfect and the healthcare worker may contaminate themselves in the process. In addition, there is no perfect manufacturing process, therefore as a manufactured product, gloves too can be defective. Thus, hand hygiene is supposed to be performed before donning and doffing of gloves.

The literature shows mixed findings in relation to hand hygiene practice when gloves are used. Marra et al. (78), Flores et al. (83) and Sanchez-Paya et al. (84) found that hand hygiene compliance is poorer when gloves are worn than when they are not used. Flores et al. attributed this in part to excessive use of gloves, even in situations where gloves are not indicated. Similarly, Fuller et al. (85) found glove use by health care workers contrary to indications for use and hand hygiene compliance much worse when gloves were used. This suggests that although gloves are not supposed be a substitute for hand hygiene, some observed practice shows the opposite. However, it should be remembered that Lankford et al. (77) found increased compliance in hand hygiene with glove use, and even suggested glove be used as a marker for hand hygiene. Pan et al. (86) also noted an increase in compliance with glove use. In their studies, Zimakof et al. (87) and Lund et al. (88) also noted minimal increase in compliance when gloves were used. These inconclusive findings when gloves are used suggest that the effect of gloves on hand hygiene is a matter that is still open to further investigation.

2.9 Reliability and Validity

Measurement is defined as the process of translating reality into numbers (89). A measurement process would therefore be necessary to evaluate the performance of electronic hand hygiene

monitoring processes or systems. The two most important and fundamental characteristics of any measurement procedure are reliability and validity (89, 90).

2.9.1 Reliability

This is defined as the extent to which a questionnaire, test, observation or any measurement procedure produces the same results in repeated trials (90). It is therefore the stability or consistency of scores over time or across raters. The reliability of an electronic hand hygiene monitoring system would therefore be a measure of the stability or consistency of the system in detecting hand hygiene events over time with all other variables held constant. Thus, any electronic sensitivity adjustments etc. must be held constant over the testing period. It should be pointed out that reliability is a measure of repeatability and not a measure of how "correct" the readings are (89, 90). Thus, an instrument that repeatedly gives the same false reading over many observations would still be classified as reliable.

There are different tests of reliability. The most common tests include test-retest reliability and inter-rater reliability (89, 90). To evaluate test-retest reliability, a test is performed and then repeated after some time, preferably by the same tester and with everything else held constant. Scores from the two tests are then compared. Reliability could range from 100%, where the scores are concurrent to 0% where there is no concurrence at all. Inter-rater reliability involves performing the same test by two different researchers holding everything else constant and comparing the scores as with test-retest (89, 90).

There are no absolute figures for good or bad reliability. However, higher figures correspond to greater reliability and vice versa. Nunnally et al. (91) suggest that processes which have at least 70% reliability can be considered reliable.

2.9.2 Validity

This is the extent to which an instrument, test or other device measures what it claims to measure (89, 90). As with reliability, there are also a number of different tests of validity. Content validity, for example, pertains to the degree to which the instrument fully assesses or measures the entire domain of content of a construct of interest. Others include construct validity which refers to the ability of a measurement tool to actually measure the theoretical construct of interest and criterion-related validity for assessment of the relationship of scores on a test to a specific criterion (89, 90).

For a detection system such as the RFID/Exciter system and other hand hygiene electronic monitoring systems, validity would be a measure of the extent to which the system detects hand washing events at wired sinks. The validity of the system would therefore be anchored in two measurements. The first measurement is how good is the system at detecting hand hygiene events? The second is, when the system detects these events, what percentage of these detections are true events and how many are false? These two measures are referred to as *Sensitivity* and *Positive Predictive Value (PPV)* (89) respectively, and their value lies between 0 and 100%. Higher values mean the validity is higher. Thus, the sensitivity and PPV of an electronic monitoring system for hand hygiene are important measures of the validity of the system.

2.10 Social and Behavioral Considerations

A more complete evaluation of hand hygiene must go beyond interventions aimed at promoting hand hygiene practice and take into consideration social and behavioral aspects of the practice. Hand hygiene practice is a human behavior and is therefore influenced by

behavioral principles Foster et al. (92). They noted the importance of this consideration thus: "The complexity of hand hygiene issues requires a solution focused on behavior change of healthcare providers and cultural change in facilities" (p.265). As with all the other approaches discussed so far, the ultimate objective of social and behavior change interventions is to improve hand hygiene practice. Social and psychological theories and models have been applied to other human health and safety behavioral practices, such as cessation of smoking, use of car seat belts. Two models that have been widely used are the Health Belief Model and the Theory of Planned Behavior.

2.10.1 Health Belief Model

The Health Belief Model was developed by taking people's readiness to act and then considering what will make them act, also called "cues to action." The model is based on four constructs, perceived susceptibility, perceived severity, perceived benefits and perceived barriers (93, 94) which represent perceived threats and perceived benefits from a course of action. An additional concept of self-efficacy accounts for one's self confidence that they can successfully perform the action, in this case hand hygiene. The core assumptions and statements of the Health Belief Model are that the healthcare worker's action will be guided by whether an individual thinks they are at risk if they do not perform hand hygiene. An individual such as a healthcare worker will also want to know how serious the risk is. The healthcare worker will also decide if the remedy, that is, performing hand hygiene, is really beneficial and too costly or inconvenient to him.

In their review to investigate the efficacy of several health theoretical models, Kretzer et al. (93) concluded that these Health Belief Model constructs can be used for prediction of behavior;

and would be useful for hand hygiene applications. However, Health Belief Model principles only make the healthcare worker ready to take action. The additional concept of *cues to action* is what enables the transition from readiness to act to overt action. In later modifications to the model, it was also considered that people need to have confidence that they can successfully execute the action. Thus, the concept of self-efficacy was incorporated into the model. Although this model has the advantage of being easy to use, this is also a disadvantage because it oversimplifies complex health issues. Moreover, as Maskerine et al. (94) point out, the model does not take into account the effect of social factors.

Although Health Belief Model can be used to predict behavior, Chen et al. (95) found its predictive power to be quite low. They applied the model to test the effect of socio-economic status as a predictor for dental visits and found a predictive power of 15-27%. Armitage et al. (96) also came to the conclusion that although the model was specifically developed for health-related applications, it has a low predictive power in these applications.

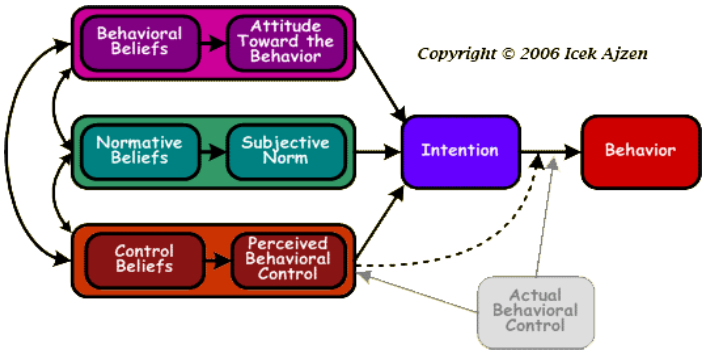
2.10.2 Theory of Planned Behavior

The Theory of Planned Behavior has been used to explain and predict voluntary human behavior. By this theory, intention precedes action, that is, if the healthcare worker intends to perform an action, such as hand hygiene, he is more likely to follow through and perform the action. This theory therefore assumes that people make rational decisions and all actions are thought through before being taken. Foster et al. (92) suggest that this is an ideal theory for hand hygiene applications. This is because although hand hygiene is a requirement in healthcare practice, it is not enforced and therefore has a voluntary component. The three considerations that guide human actions under this theory are Behavioral Beliefs, Normative

Beliefs and Control Beliefs (97). Behavioral Beliefs are beliefs about the likely consequences of the behavior. In the hand hygiene context, these can be summarized as the healthcare worker's beliefs about the utility and effectiveness of hand hygiene. Normative Beliefs refer to beliefs about the normative expectations of others. This is the perceived social pressure. What do my colleagues think about hand hygiene? Control Beliefs are beliefs about the presence of factors which may facilitate or impede performance of the behavior. These constitute the healthcare worker's perceived control over elements that promote or hinder hand hygiene compliance. Control Beliefs are similar to the concept of self-efficacy as discussed in the Health Belief Model. Control Beliefs are therefore the degree to which the healthcare worker believes he can successfully perform the task, that is, hand hygiene.

Figure 2.2 shows how these three considerations relate with each other under the Theory of Planned Behavior, Ajzen (98).

Figure 2.2: Conceptual Model for Theory of Planned Behavior



Based on the Theory of Planned Behavior, Foster et al. (92) concluded that interventional studies focusing on behavior change should concentrate on addressing three elements, social pressure, attitude of staff towards hand hygiene and worker control over work-related aspects

of hand hygiene; that is, instillation of confidence that the healthcare worker can successfully perform hand hygiene practices.

From the Theory of Planned Behavior, Ajzen (97) concluded that a behavior is predictable and therefore modifiable. In their meta-analysis on the efficacy of the Theory of Planned Behavior, Armitage et al. (96) concluded that the theory is a predictor of intentions and behavior, especially self-reported behavior. Blue's exploration (99) of the predictive capacity of the theory is consistent with this conclusion. Her findings show that belief about a behavior correlated positively with attitude; while normative belief positively correlated with subjective norm. In their comparative meta-analysis of models of preventive health behavior, Zimmermann et al. (100) found that the Theory of Planned Behavior was a better predictor of health behavior than the Health Belief Model. The findings of other reviewers have similarly supported the effectiveness of the theory when applied for behavior prediction (99, 101-103). As an example, the findings of Haas et al. (59) and Backman et al. (104) show that senior management buy-in and their active involvement in hand hygiene initiatives is associated with improved hand hygiene compliance. This can be viewed as a form of social pressure or normative beliefs.

By the Theory of Planned Behavior therefore, hand hygiene practice is also going to be governed by beliefs regarding the likely consequences of complying or not complying. The same reasoning would apply regarding using the correct hand hygiene technique, and even whether to opt for hand washing or use of alcohol hand-rub. Findings from a qualitative study by Erasmus et al. (105) to explore reasons for poor hand hygiene compliance highlight the importance of beliefs and social pressure. Interviews were given to 65 nurses and physicians in

intensive care units and surgical departments in five hospitals. Analysis of the data led to the conclusion that beliefs about the importance of self-protection are the main reason for performing hand hygiene.

Moreover, Erasmus et al. (105) concluded that a lack of positive role models and social norms may hinder compliance. From these findings, it is evident that in hand hygiene applications, behavioral and social considerations ought to receive more attention than they currently do. This centrality of behavioral and social factors is evident in the conclusion by Foster et al. (92) that, "Thinking about behavioral barriers and human behavior change theory may be more revealing than assuming that protocols and easy access to hand hygiene products are the ultimate solution to improving compliance"(p.266).

According to the Theory of Planned Behavior therefore, a nurse's decision about whether or not to perform hand hygiene, when to perform hand hygiene, what method to use, and what technique to employ when performing the hand hygiene, will be made on the premise of the likely consequences of not performing it. But the theory also recognizes that not all actions taken by an individual are fully volitional. Thus, the theory allows for some behavior outside the intentional channel.

The Theory of Planned Behavior is an approximate representation of the complex dynamics associated with behavior, in this case performance of hand hygiene. The theory therefore has its strengths and weaknesses (96, 99).

Strengths and Weaknesses of the Theory of Planned Behavior

Strengths

The Theory of Planned Behavior takes into account non-volitional behavior. This is strength is an advantage over its predecessor, the Theory of Reasoned Action, which had assumed that all behavior was volitional. The Theory of Reasoned Action is the same model as the Theory of Planned Behavior, but without the *actual behavioral control* component.

Although the theory holds that intention precedes and predicts behavior, an individual's intention to perform a behavior cannot be the only determinant of behavior where the individual does not have full control over the behavior. By adding "perceived behavioral control", the Theory of Planned Behavior can explain the relationship between behavioral intention and actual behavior. The theory also takes into account the social element as an important component in the lead up to a behavior or an action. By this theory therefore, the influence of social pressure on behavior is taken into account.

Weaknesses

The theory does not take into consideration demographic factors or variations in individuals. These factors, which may have influence over a behavior, include level of education, sex, age etc. The theory also assumes that perceived control over behavior predicts actual control over the behavior. In the hand hygiene context, the assumption is that if the healthcare worker is convinced he or she has control over their hand hygiene practice; they actually do have control over the practice. This is an assumption that has not been validated, and therefore one that is not necessarily true.

Applicability of the theory is possible only when some aspects of behavior are not under voluntary control. When the entire behavior is under voluntary control, the Theory of Planned Behavior becomes the Theory of Reasoned Action, which presumes that all action is under the voluntary control of the individual. Also, the longer the time interval between behavioral intent and behavior, the less likely the behavior will occur. Thus, for effectiveness, the Theory of Planned Behavior presumes that a behavior will be performed shortly after the intention to perform it. The Theory of Planned Behavior does not take into consideration delays and subsequent non-performance of the behavior.

The Theory of Planned Behavior further assumes that human beings are always rational and make systematic decisions based on available information (106). Thus, every voluntary hand hygiene act is assumed to be reasoned out. An additional weakness is that the theory does not take into consideration unconscious motives for a behavior.

Therefore, despite its many advantages, the Theory of Planned Behavior also has a number of significant disadvantages. These disadvantages should be taken into consideration when applying the theory for hand hygiene applications.

2.10.3 Culture

According to the Theory of Planned Behavior, social pressure has a bearing on compliance with a behavior (97, 100). But social behavior is anchored in culture (95, 107-109). Thus culture is an important concept that must be taken into consideration when evaluating hand hygiene practice. This was the conclusion that was arrived at by Allegranzi et al. (110) in their study on the effect of religion and culture on hand hygiene practices. However, there is very little evidence of research on the effect of culture on hand hygiene practices.

In social sciences, organizational theory points out that every organization has its own unique culture (107, 109). Further still, within the wider organization, there are internal cultural variations local to the different departments and branches (107-109, 111). Thus, in the healthcare setting, the entire hospital has its own general culture; and nested within this are sub-cultures for the individual patient-care units. The healthcare worker's hand hygiene culture is thus forged and influenced by her background, including home, family and community as well as the work environment. The complexity of human behavioral considerations as applied to hand hygiene is summed up in the following observation by the World Health Organization (29): "Human health-related behaviour is the consequence of multiple influences from our biology, environment, education, and culture. While these influences are usually interdependent, some have more effect than others; when the actions are unwise, they are usually the result of trade-offs with acknowledged or denied consequences. Thus, this complexity of individual, institutional and community factors must be considered and investigated when designing behavioural interventions and when exploring to understand individuals' hand hygiene practice."

2.11 Grounded Theory

Inquiry into social phenomena or psychological concepts such as behavior is normally conducted using qualitative approach (112-116). Unlike quantitative approaches which look at the external, measurable perspectives of human behavior, qualitative approaches look at both external and internal or inner perspectives (112-114). These internal perspectives emphasize the importance of mental and social processes (112, 114). Qualitative approaches are therefore useful for exploring social and behavioral aspects of hand hygiene. Qualitative inquiry

is conducted using one of several traditions (112). One of the most popular traditions is *Symbolic Interactionism* (112, 114-118*).* This tradition assumes that one's communication and actions express meaning. This is the tradition upon which Grounded Theory methodology is founded. This methodology further assumes that meaning is dynamic and that it is shared by group members (112, 115, 118).

Like other qualitative approaches, Grounded Theory employs an inductive approach to inquiry (112-120). In contrast to quantitative approaches, which use deductive processes, that is, from the general theory to specific observations, Grounded Theory and other inductive approaches proceed from specific observations to the formulation of a general theory (117-122). When Grounded Theory methodology is used, data may be collected from various methods and sources including observing and recording interactions, examining written documents and literature or obtaining perspectives from various people involved in the social interaction (115, 118, 120).

The method used to arrive at the grounded theory is called the *constant comparative* method (113-122). By this method, data is collected and analyzed concurrently to generate the theory. This continuous back-checking of the emerging theory against data ensures that the theory is indeed grounded in the data (113-122). If any gaps are identified in the emerging theory, specific participants are targeted for further observation or interview. This process is referred to as *theoretical sampling* (112, 115, 119) and it is aimed at filling the gaps in the emerging theory. Thus, while deductive approaches prescribe a theory externally and then seek to confirm it, inductive approaches, such as Grounded Theory generate the theory from the data. As the analysis continues, the researcher looks for key variables which will be central for theory

generation. This core variable recurs frequently, links various data and generally includes people from various backgrounds (113-117).

Data are typically coded at three levels. The first level is a line by line examining of the data. This is followed by comparing and contrasting of the data to produce categories (114, 116-118). The final stage is development of the theory. Saturation is considered to have been achieved when there is no new information coming from additional data collection. Saturation is therefore an important signal to stop collecting additional data (117, 118).

2.11.1 Sensitizing Concepts

Although Grounded Theory is an inductive model of inquiry, it also has deductive aspects (117, 118, 120, 121). One key deductive aspect in the theory is the practice of reviewing the literature for theoretical background. However, this aspect is supposed to be used for comparison with emerging concepts and not for theory generation. In this way, the literature and prior theoretical knowledge and concepts can be used as a 'bracketed' reference or *sensitizing concepts*. Blumer (123) differentiates between a definitive concept and a sensitizing concept thus: "Whereas definitive concepts provide prescriptions of what to see, sensitizing concepts merely suggest directions along which to look" (p.7). Definitive concepts are the concepts emerging from the data, and from which the theory is ultimately derived.

2.12 Summary

Technology in Hand Hygiene Applications

Studies on electronic monitoring of hand hygiene practice mainly focus on intervention and measurement of compliance. There is minimal work being done on hand hygiene technique and

validation of the electronic measurement tools. Thus, when electronic tools are used, there is no mention of their reliability or validity.

Many studies using electronic technologies use proxy variables to represent hand hygiene compliance. However, these variables do not always correlate directly with the actual hand hygiene events that they are supposed to represent. One of the biggest methodological weaknesses in using these variables, especially in measurement studies, is the assumption that walking into a patient room or being in a patient's personal zone constitutes a hand hygiene opportunity. The inability of these systems to pick up multiple hand hygiene opportunities while the participant is within the patient zone further shows the weakness of this approach. Moreover, the existing electronic monitoring capabilities are unable to identify two key hand hygiene moments: before aseptic procedure and after exposure to body fluids.

Hand Hygiene Practice

Results from numerous studies show that hand hygiene compliance after patient contact is always much higher than before patient contact (52, 64, 77, 79-82). The need for self-protection has been suggested to be the main motivator behind performance of hand hygiene by healthcare workers (77, 105). Glove use has also been shown to directly correlate with hand hygiene (77, 105). But do healthcare workers subconsciously grade the risk and perform hand hygiene accordingly?

The literature shows that there are few studies on quality of hand hygiene, especially hand washing. This is surprising given that the effectiveness of hand washing has been shown to be much more susceptible to poor technique that when alcohol hand-rub is used. In addition, existing guidelines for hand hygiene technique are largely based on expert opinion with little

rigorous scientific backing. Although alcohol hand-rub has taken over as the primary method for performing hand hygiene, there are still instances when caring for patients requires use of soap and water. Thus, there is still a need for methodologically sound research into hand washing technique.

Social and Behavioral Considerations

Hand hygiene compliance and technique have generally remained poor despite many interventions. There is an emerging awareness that social and behavioral considerations need to play a bigger role in understanding hand hygiene practice and therefore improving it (92). But an understanding of governing relationships and associated variables are necessary before implementation for change. Both the Theory of Planned Behavior and the Health Belief Model have been shown to have predictive capability on health-related behavior such as hand hygiene (93, 95). The concept of culture has also been shown to be ubiquitous, influencing all aspects of our life (107-109). Thus these models as well as the concept of culture would be helpful as *sensitizing concepts* in the development of a theoretical foundation under the Grounded Theory model of inquiry.

SUB-STUDY 1

CHAPTER THREE

METHODOLOGY

3.1 Introduction

The research question to be addressed in this sub-study was: Is a Radio Frequency ID/Exciter system (RFID) a valid tool for detection of hand washing events in the healthcare setting? In this chapter, the background to this sub-study and methodology used are described. Methods used for sample design and data collection, as well as their rationales and strategies employed to limit bias are explained. Data management and analysis techniques used are also described.

3.2 Background

At the time of launching this study, there was an ongoing study in Unit 36 at the Foothills Medical Centre in Calgary, Alberta. The study employed real-time locating systems technology (RTLS) and was in the third of four phases. The purpose of the study was to implement real-time electronic tracking of healthcare workers and equipment with the aim of enhancing patient safety and improving quality of healthcare. The first phase was to document the process of implementing RTLS technologies in the hospital setting. The emphasis in this phase was to test the RTLS system and document the challenges and barriers encountered in using it. The second phase was to pilot-test the technology's performance once implemented. The goal of this phase was to assess the technology's performance and validate time-location data produced by the technology. A comparison was then made between what the technology was reporting to be the physical location of a tagged medical device and the actual location as reported by an observer.

These two phases were followed by an application phase whose objective was to develop real-time observational measurements tracking both motion and location. This was done for both healthcare workers and mobile medical equipment. The data collected was used to create a real-time/location map which would then be used to analyze healthcare provider mobility and workflow patterns.

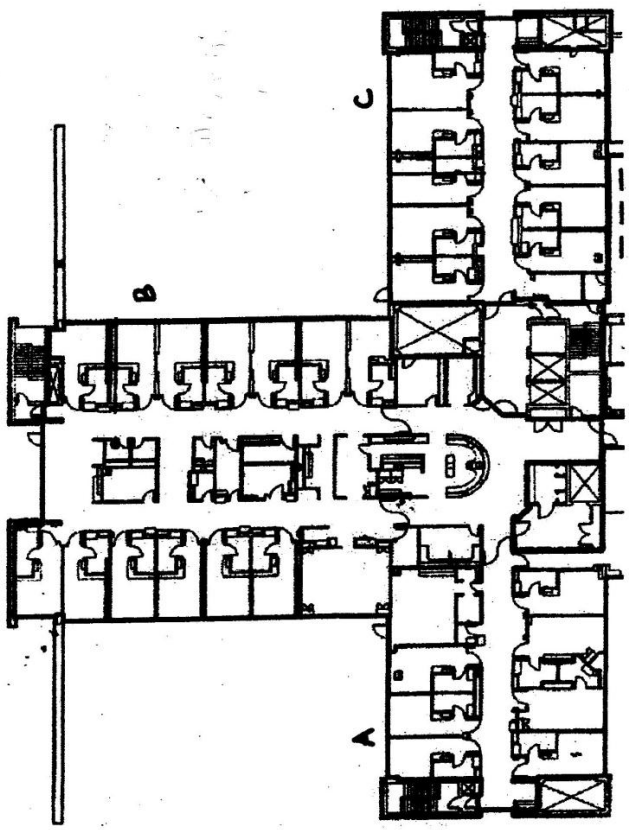
The final phase was to assess the performance of observational analysis of healthcare workers' activities related to patient-care and infection control practices. This would involve using RTLS technology to monitor healthcare workers' hand hygiene practices. These first three phases were outside the scope of the current sub-study. This sub-study is phase 4 of the RTLS study.

3.3 METHODS

3.3.1 Setting

The sub-study was conducted in Unit 36 at the Foothills Medical Centre, a Level A-1 trauma, teaching hospital located in Calgary, Alberta. Unit 36, also known as the Ward of the 21st Century, is a modern 30-bed acute-care in-patient medical unit at the hospital. The unit has a three-wing layout as shown in Figure 3.1. This sub-study was conducted in the 'C' wing.

UNIT 36 LAYOUT



3.3.2 Study Design

This was an observational study.

3.3.3 Study Population

The population for this study included all 85 registered nurses who worked on the unit. Of these, 53 worked full-time and 32 worked as casuals.

3.3.4 Sample Design

Every nurse who worked full-time had her own rotation schedule. Casual employees also had their own lighter schedules, but they could be called for additional coverage when the need arose. For any work shift on the unit, two nurses were assigned to the 'C' Wing. The duty roster was prepared on the material day; but could be revised without notice due to sick calls, sudden changes in patient acuity and other unpredictable factors. It was therefore not possible to know beforehand which nurse would be assigned to the wing on which day. This made it difficult to make a true random selection of participants from the study population, and obtain consent from them in advance.

The variable and unpredictable assignment meant that some nurses stood a chance of being observed multiple times while others who were never assigned to the wing had no chance. Sample size calculation was therefore considered impractical and was thus not performed. Convenience sampling with observation on at least 25% of the population was considered adequate and was adopted. This is a non-probability sampling method where participants are selected because of their convenient accessibility to the researcher (114. p.118).

3.3.5 Hand Washing Event

As part of the RTLS study, exciter modules had been installed at selected hand hygiene sinks in the 'C' wing of the unit. The module is an electronic device and was mounted on the wall, about 10cm directly above the sink. A total of three corridor sinks and three patient room hand hygiene sinks had been fitted with the modules. Figure 3.2 shows the location of these wired sinks.

Selection of sinks to wire with exciters had been performed and completed under the RTLS study. Consideration regarding which sinks to wire was therefore not part of the study design for this sub-study. However, the fact that corridor sinks are known to be used more frequently for hand hygiene than room sinks (18) is likely to have informed the wiring of all corridor sinks.

The RFID tag is a thin electronic card about the size of a standard ID badge. It was worn on the participant's lanyard, alongside the staff ID badge and *Vocera* communication module. The tag had two adjustable time settings: *dwell time* and *reset time*. If the tag came within the sensing range of the wall-mounted exciter module, and dwelt there for a preset time, that is, the *dwell time*, the system would trigger and record that an event had occurred. This event recording could be observed on the system computer and printed out if required. The definition of an event was therefore based on the dwell time of the RFID tag.

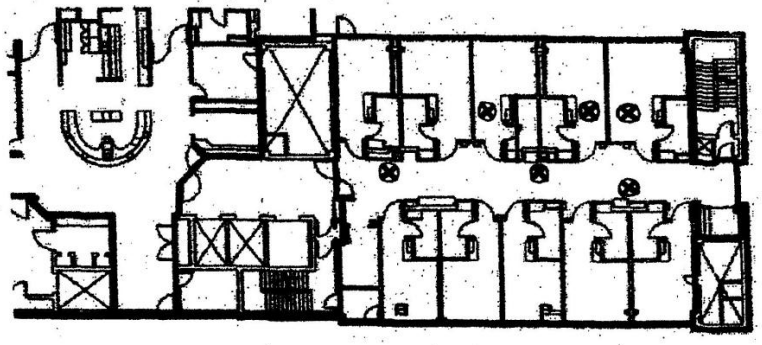
Electronic sensitivity adjustments were made to the tag to ensure an event only registered if the participant, with the tag at chest level, bends over at a wired sink and dwells there, in that position for at least the duration of the dwell time. An event that registered on the RFID/Exciter system was therefore considered to be a hand washing event. The assumption made was that in the work environment, a healthcare worker in that position, at a sink and for that minimum

duration is most likely to be washing hands. In this study, this assumption is referred to as **Assumption 1**. The purpose of the dwell time was to minimize the chances of recording false events, such as when a participant merely passes by a wired sink.

The *reset time* was the minimum time that had to elapse after an event had registered, but before the system could accept another event to register. This time was therefore a temporal spacer separating one event from the next. Thus the time between events could be longer than the reset time, but it could not be shorter. The purpose of the reset time was to prevent nuisance triggering or multiple registration of the same event.

WIRED SINK LOCATIONS

Wing 'C'



Key:

Wired sink location

3.3.6 Ethical Considerations

Before any part of this study was undertaken, the proposal was submitted to the Conjoint Health Research Ethics Board (CHREB) of the Faculty of Medicine of the University of Calgary; and approval to proceed granted. Attached in Appendix A is a copy of the letter of approval. This study was an epidemiologic observational study with no interventional involvement. Participation in the study entailed minimal risk. The principle of non-malfeasance was thus incorporated into the study. Moreover, the ultimate objective of the study was to improve hand hygiene during patient-care. This would result in fewer HAIs, which would be beneficial to the wider society. This objective was therefore in line with the ethical principle that requires that studies be of utility, either to individuals or to society at large.

Despite these ethical design considerations, participants were given all the extra details necessary to make informed decisions about participation. These details were in the consent forms (Appendix B and C). The autonomy of participants was upheld, and it was made clear to them that that they were free to withdraw from the study at any moment and without any conditions. Thus, the study was designed to be beneficial to society while upholding the autonomy and respect of every participant. These ethical conditions applied to the entire study, including all three sub-studies.

3.3.7 Data Collection

The observer came to the unit just before shift change. The first thing to do was to synchronize his real-time watch with that of the RFID/Exciter system, as the system recorded all its events in real-time. This synchronization of clocks was therefore the anchor linking system-recorded events with those recorded by the observer.

The RFID tag to be used was then tested at a wired sink to ensure that events were picked up and recorded by the system as per design. During this testing, care was taken not to attract any undue attention. The purpose of this was to keep the nurses on the unit blinded to the kind of data being collected.

At start of an observation session, the observer approached either of the two nurses assigned to the 'C' Wing of the unit and requested to be allowed to observe the nurse as she went about her duties. If the nurse agreed, she was given a copy of the consent form (Appendix B) to review and ask questions if any. After the form had been signed by both the nurse and the observer, the nurse was given her copy of the form. The observer retained the original copy. The nurse was then assigned a unique identification number. This number and the nurse it represented were known only to the observer. No personal identifiers or trace-back mechanisms were attached to the number. The purpose of this was to ensure the participants remained anonymous and the data collected could not be linked to any particular individual. If the nurse turned down the request to be observed, the request was made to the other nurse assigned to the wing. If both declined, the observation for that shift was canceled.

The signed consent form was valid for that observation session only. This principle was adhered to even for repeat observations of the same nurse on different days. However, any repeat nurse retained the original assigned identification number. The nurse was then given the pre-tested tag and asked to wear it at chest level alongside her ID badge. This same tag, labeled 'Nurse 02' was used for all RFID observations in this study. The *dwell time*, *reset time* and electronic sensitivity settings that had been set at the beginning of the Study Period were maintained over the rest of the study.

Potential ethical concerns in relation to non-disclosure of the actual data being collected were recognized at the study design stage. However, it was felt that this blinding was necessary in order to ensure integrity of the data and validity of the findings. In addition, it was felt that matters of ethics had been adequately addressed in the informed consent form. Conjoint Health Research Ethics Board (CHREB) did not object to this approach.

Data for sub-study 1 and sub-study 2 were collected concurrently using the data collection worksheet shown in Figure 3.3. In this section, only the sections of the worksheet that are relevant to sub-study 1 are discussed. Sections that are relevant exclusively to sub-study 2 will be discussed under sub-study 2.

A hand hygiene opportunity was defined as any one of the moments on the *WHO's My Five Moments for Hand Hygiene* shown in Figure 2.1. If an opportunity arose, the observer recorded the time of the opportunity in the *Time* column of the data collection worksheet. If hand hygiene was performed for that opportunity, 'Y' was entered in the '*HH Opportunity Utilized*?' column. An 'N' was entered if none was performed. The duration of the observed hand hygiene act was entered in the '*HH Duration'* column. Data from this direct observation for both hand hygiene compliance and duration were recorded for all hand hygiene events, including events at wired or unwired sink as well as hand hygiene events at alcohol hand-rub stations. However, only data for the wired sinks were used in this sub-study.

Sinks and alcohol hand-rub stations were assigned reference numbers based on their location. Thus, A3622 would represent alcohol hand-rub station in room 3622, while S3625/7 would be corridor sink between rooms 3625 and 3627. The sink or alcohol hand-rub station where the hand hygiene was performed was recorded in the *Sink/Gel Station* column of the data

collection worksheet. The patient room where the opportunity occurred was recorded in the *Room* column and any additional comments entered in the *Comments* column. All durations were in seconds.

At wired sinks, the observer made use of exciter-mounted LEDs to measure duration. Each exciter module had one prominently mounted LED which was blinking at the rate of one flash per second. At the non-wired sinks and alcohol rub stations, the observer quietly counted "one-thousand-and-one, one-thousand-and-two,…" as an approximation for a one second interval. This had been tested against an exciter LED flash rate and found to be reasonably accurate. Care was taken to ensure that the participant did not associate visit to a sink or alcohol hand-rub station with observer writing. To this end, techniques such as intentional delayed writing in relation to an observed event and pretend writing during non-hand hygiene-related events were employed. The aim of this was to minimize potential hand hygiene behavior modification by Hawthorne Effect. If the nurse closed the door or drew a curtain, the observer assumed no hand hygiene opportunity or compliance had occurred. Recording was done only for opportunities that were witnessed. At the end of an observation session, a summary was made. This summary included any peculiarities or unusual occurrences that had been observed.

The observer scheduled the sessions to ensure that data were collected from all three work shifts, that is day, evening and night. The aim of this was to ensure that any possible variation in hand hygiene practice across shift lines was captured. This element of observing during different shifts, the unpredictable availability of the observer as well as not knowing which nurse would be assigned to the 'C' Wing on which day, were design measures incorporated to help minimize selection bias.

Fig 3.3: DATA COLLECTION WORKSHEET

Date: _____ Shift_____ Ref. No. _____ Observer Initials: _____ Worksheet Number: _____

	Time	HH Opportunity Utilized?	Gloves	HH Duration	Perceived Risk Factor	Sink/Gel Station	Isolation Status	Room	Comments
1.									
2.									
3.									
4.									
5.									
6.									
7.									
8.									
9.									
10.									

Key:

Time: Time of the day e.g. 1015, 2211 or 4:30PM

HH Duration: Time in seconds, actually washing or rubbing gel.

Isolation Status: 0=None, 1=Contact, 2=Droplet, 3=Airborne

HH Opportunity Utilized?: Y =Used, N = Did not use

Risk Factor: E.g. H2, L1

Designation/Ref No.: E.g. N-17 or N-03

Gloves: Were gloves worn?: Y or N

Sink/Gel Station: E.g. S1 or G2

Room: Room No. E.g. 371

Comments: Any additional info e.g. talking while washing hands etc

Data collection was divided into two periods: Trial Period and Study Period. When the *dwell time* and *reset time* of the RFID/Exciter system were tested and adjusted, actual hand hygiene behavior was being observed. This period was the Trial Period. Although the recommended duration for effective hand washing is at least 15 seconds (30), it was observed during this period that whenever nurses washed their hands, it was for much shorter durations than the recommended minimum duration. The objective of this sub-study was to test validity of the technology and not to see whether nurses perform hand hygiene for the recommended duration. Therefore, to give the system a chance to detect events, *dwell time* was lowered to five seconds during the Trial Period. The *reset time* was retained at one second.

During the Study Period, the *dwell time* was further adjusted downwards to one second. It had been observed during the Trial Period that even a five-second *dwell time* was too long for most nurses who had been observed. The average duration had been observed to be typically two or three seconds.

3.3.8 Sink Utilization

Any hand washing performed at an un-wired sink could not be detected by the RFID/Exciter system. If the proportion of these undetectable events as compared to all hand washing events was significantly large, the RFID/Exciter system would miss many potential hand washing events.

Sink utilization was the proportion of all observed hand washing events that were potentially detectable in comparison to all observed hand washing events. A high value would indicate that the correct sinks had been wired.

Data were collected on varying days from December 1, 2009 up to February 18, 2010, inclusive of both days.

3.3.9 Data Management

Collected data were reviewed for accuracy then entered into STATA IC 10 statistical software for analysis.

3.4 ANALYSIS

3.4.1 Validity

Data collected during the Trial Period were omitted from analysis as the *dwell time* for this period was different from that of the Study Period. Events recorded during the *study period* by the observer and those recorded by the RFID/Exciter system were entered in Table 3.1. These events were categorized as True Positives, False Positives, True Negatives and False Negatives.

True Positives (TP): Events that were witnessed by the observer and also detected by the Radio Frequency ID/Exciter system

False Positives (FP): Events that were not recorded by the observer but were registered as detected by the system

False Negatives (FN): Events that were witnessed and recorded by the observer, but were not detected by the system

True Negatives (TN): Events that were not recorded by the observer or by the system

Table 3.1: RFID/Exciter Detections

		Observer	
		Yes	No
RFID Detector	Yes	TP (a)	FP (b)
	No	FN (c)	TN (d)

The detection system's Sensitivity, Positive Predictive Value and Specificity were then calculated.

Sensitivity (Power to Identify Positives)

Sensitivity (p) = TP/(TP + FN)

Standard Error (S_e) = $\sqrt{p(1-p)/n}$

95% Confidence Interval for Sensitivity therefore equals

$p \pm 1.96*(S_e)$

Positive Predictive Value, PPV (Probability that a Positive is True)

PPV = TP/(TP + FP)

Standard Error (S_e) = $\sqrt{p(1-p)/n}$

Specificity (Power to Identify Negatives)

Specificity = TN/(TN + FP)

The PPV and Sensitivity define the validity of the system thus, the higher the values the higher the validity of the system.

3.4.2 Reliability

Test-retest reliability for the system was assessed. This test was selected over other types of reliability for several reasons. There was only one observer over the entire study duration. It was therefore not possible or practical to assess for inter-rater reliability. Moreover, the same RFID electronic tag with pre-set *dwell* and *reset* times was used for all participants and at all wired sinks over the different days and times of observation. In addition, the observer pre-tested the tag at a random wired sink at the start of every observation period. Also, field use of

the RFID/Exciter system would expose it to numerous potential hand washing events. It was considered important to assess how reliable the performance of the system would be when subjected to these conditions. *Detection Score* (*DS*) was defined as

(Number of detected events / Number of detectable events) * 100

This value was calculated for each observation session for both the observer (during the tag pre-test) and the nurse (during the observation period). These scores were labeled as *DS_Observer* and *DS_Nurse* respectively.

From these two sets of *Detection Score*, reliability was calculated thus:

Test-Retest Reliability = (Number of observation sessions when both *DS_Observer* and *DS_Nurse* detected events) / (Number of observation sessions where there were detectable events)

3.4.3 Sink Utilization

As the selection sink selection for wiring was not part of this sub-study, yet detection of events at wired sinks was a central component of the study, it was considered important to know the proportion of hand washing events that were performed at wired sinks. From this, it would be possible to assess if too many hand washing events are undetectable by virtue of being performed at un-wired sinks.

Sink utilization =

(Number of hand washing events observed at wired sinks)/ (Total number of observed hand washing events)

This figure was calculated from observed sink usage and did not depend on RFID/Exciter detection of an event. Thus observations from both the Trial and Study periods were used in its calculation.

CHAPTER FOUR

RESULTS

4.1 Introduction

This chapter covers results for both the Trial and Study periods. Events that were detected and those that were missed are investigated. These results are then analyzed and the performance of the system as a tool for detection of hand washing events is determined. This is achieved by calculation of sensitivity and positive predictive value. Also calculated is sink utilization.

4.2 Trial Period

A total of ten hand washing events were observed; seven of them at wired sinks. None of the ten crossed the detection threshold of five seconds and therefore none was detected by the RFID/Exciter system. No false positives were detected. During this period, nurses were observed to wash hands for durations lasting between two and four seconds. Table 4.1 shows the frequency distribution for all the hand washing events that were observed during this period.

Table 4.1: Witnessed Handwashing Events during Trial Period

Hand washing duration (seconds)	Total observed	Total observed at wired sinks
2	5	4
3	3	1
4	2	2

4.3 Study Period

As the definition of an event was based on *dwell time*, all data that were collected during the Trial Period were omitted from this section. Table 4.2 gives a summary of observations from the

Study Period. From a total of 333 hand hygiene opportunities, 140 were utilized, 47 of them being hand washing.

Table 4.2: Summary of Observations: Dwell Time = 1 second

Variable	Count
Total hand hygiene opportunities	333
Total hand hygiene opportunities utilized (hand washing + alcohol hand-rub)	(47 + 93) = 140
Total hand washing events	47
Total hand washing events at wired sinks (i.e. potentially detectable events)	40
Total true detections (i.e. True Positives)	7
Total true events not detected (i.e. False Negatives)	33

The RFID/Exciter system also made two false detections. One was a participant pulling out a paper towel at a sink. This event was not related to any hand hygiene opportunity and the nurse had not even performed any hand hygiene. The nurse randomly, and for no apparent reason, just reached out for a paper towel from the dispenser. Although the nurse dwelt at the sink for at least the duration of the dwell time and occasioned detection, this event was observed, by direct observation, not to be an actual hand washing event. It was therefore classified as a false positive.

The other false detection was an unknown event that occurred inside a patient's room. This event was also classified as a false positive. Table 4.3 shows a summary of the seven valid and two unknown detections that were made by the RFID/Exciter system.

Table 4.3: Events Detected by RFID/Exciter System

Detections			
Date	**Time**	**ID Tag**	**Description**
5-Jan	9:37	Nurse 2	Unknown
5-Jan	9:50	Nurse 2	Valid
5-Jan	10:17	Nurse 2	Valid
6-Jan	10:38	Nurse 2	Valid
6-Jan	10:44	Nurse 2	Valid
6-Jan	10:46	Nurse 2	Towel (false)
12-Jan	17:00	Nurse 2	Valid
20-Jan	15:45	Nurse 2	Valid
20-Jan	15:58	Nurse 2	Valid

Figure 4.1 is the event recording for a typical observation session. In this example, three events were detected. The detailed information about these events is given in Figure 4.2. Three similar ID tags were available for use. They were labeled 'Nurse 01', 'Nurse 02' and 'Nurse 03.' The tag labeled 'Nurse 02' had been used for this observation session. These sample observations were made on January 6, 2010.

Figure 4.1: Event History Report 1

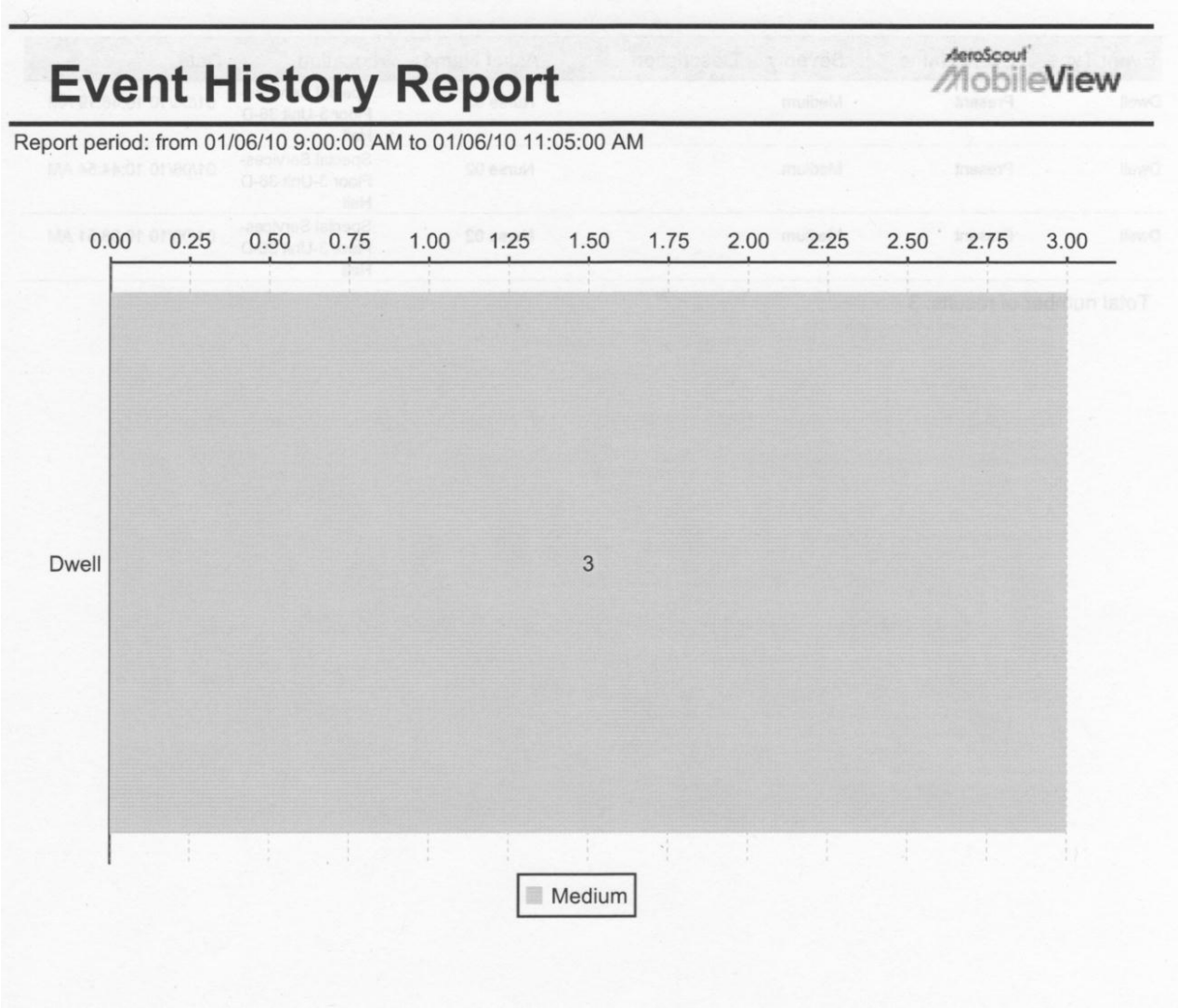
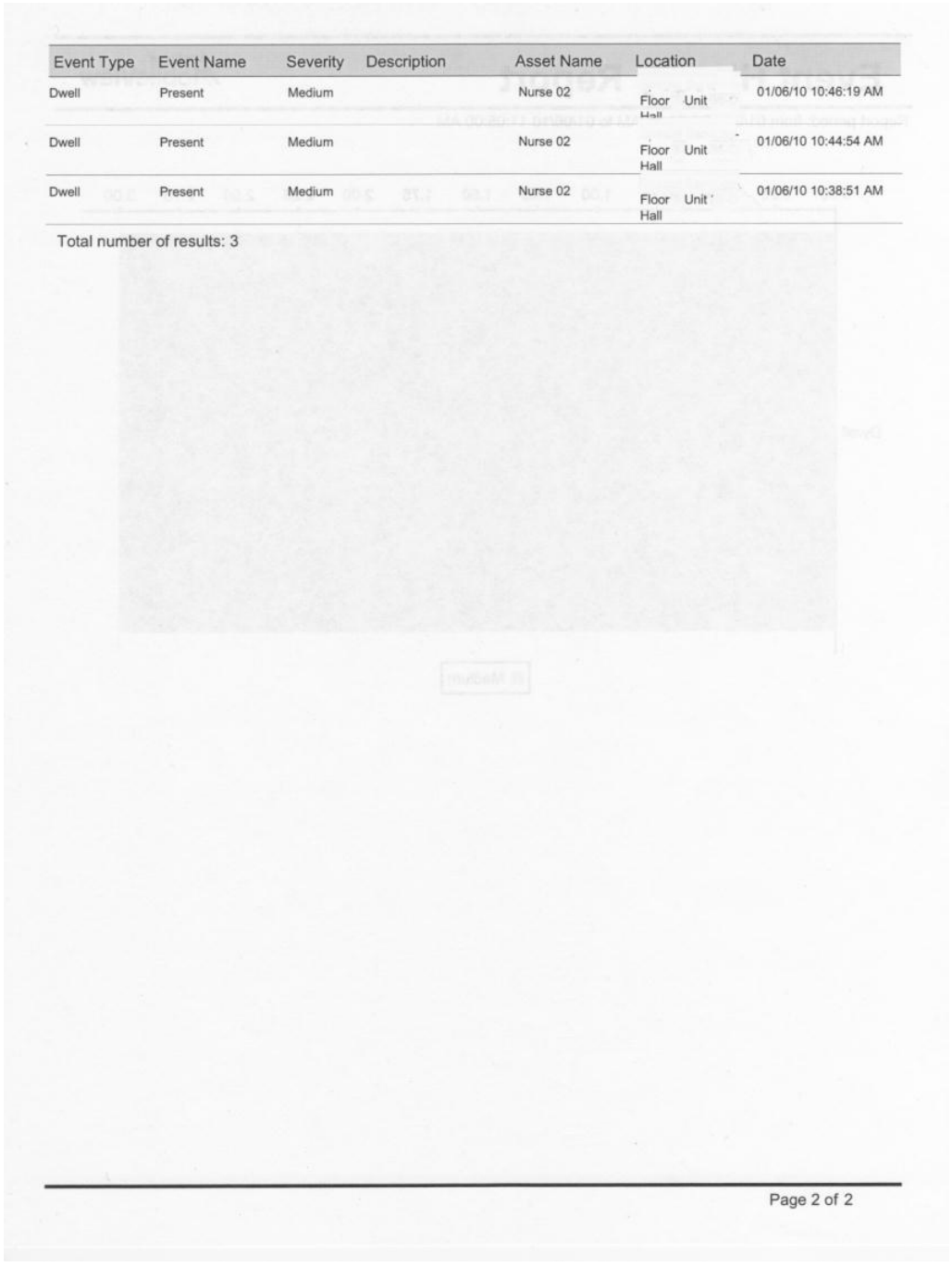


Figure 4.2: Event History Report 2



Event Type	Event Name	Severity	Description	Asset Name	Location	Date
Dwell	Present	Medium		Nurse 02	Floor Unit Hall	01/06/10 10:46:19 AM
Dwell	Present	Medium		Nurse 02	Floor Unit Hall	01/06/10 10:44:54 AM
Dwell	Present	Medium		Nurse 02	Floor Unit Hall	01/06/10 10:38:51 AM

Total number of results: 3

Page 2 of 2

4.4 ANALYSIS

4.4.1 Validity

Table 4.4 is the 2X2 contingency representation of all events at wired sinks. It shows that there were seven true positives, two false positives and 33 false negatives.

Table 4.4: Summary of all Potentially Detectable Hand Washing Events

		Observer	
		Yes	No
RFID Detector	Yes	TP (a) 7	FP (b) 2
	No	FN (c) 33	TN (d) -

From these events, Sensitivity, Positive Predictive Value and Specificity of the RFID/Exciter system were calculated.

Sensitivity (Power to Identify Positives)

Sensitivity (p) = TP/(TP + FN)

= 7/(7 + 33)

= 0.175

Standard Error (S_e) = $\sqrt{p(1-p)/n}$

= $\sqrt{0.175(1-0.175)/40}$

= 0.060

95% Confidence Interval for Sensitivity therefore equals

p ± 1.96*(S_e)

= 0.175 ± 1.96*0.060

= 0.175 ± 0.118

Sensitivity, *p,* of the Radio Frequency ID/Exciter hand washing detection system is therefore

0.175 [0.057, 0.293]

Positive Predictive Value, PPV (Probability that a Positive is True)

PPV = TP/(TP + FP)

= 7/(7+2)

= 0.778

Standard Error (S_e) = $\sqrt{p(1-p)/n}$

= $\sqrt{0.778(1-0.778)/40}$

= 0.066

95% Confidence Interval of PPV, therefore equals

0.778 ± 1.96*(S_e)

= 0.778 ± 1.96*0.066

= 0.778 ± 0.129

Therefore PPV = 0.778 [0.649, 0.907]

Specificity (Power to Identify Negatives)

Specificity = TN/(TN + FP)

There were no observations made for true negatives. Specificity was therefore not calculated.

4.4.2 Reliability

During the Study Period, there were 24 observation sessions. At the beginning of each of these sessions, the electronic tag had been pre-tested. During the observation session, there were opportunities for event detection at wired sinks. Table 4.5 gives a summary of the detection

opportunities and actual detection for both the observer during pre-test and the nurse during actual observation. All pre-testing had one opportunity each. And the event was detected for each opportunity. Thus, *DS_Observer* had a score of 100% for all the 24 observation sessions.

Table 4.5: Event Detections for Observer and Nurses – All Observation Sessions

Observation Session	Observer Pre-Test			Nurse Scores			
	Opportunities	Detected	*DS_Observer*	Opportunities	Detected	*DS_Nurse*	Nurse
1 (Dec 8)	1	1	100	0	0	-	4
2 (Dec 10)	1	1	100	0	0	-	5
3 (Jan 5)	1	1	100	2	2	100	6
4 (Jan 6)	1	1	100	2	2	100	7
5 (Jan 8)	1	1	100	1	0	0	8
6 (Jan 10)	1	1	100	2	0	0	9
7 (Jan 11)	1	1	100	0	0	-	10
8 (Jan 12)	1	1	100	1	1	100	11
9 (Jan 16)	1	1	100	0	0	-	3
10 (Jan 16)	1	1	100	4	0	0	12
11 (Jan 17)	1	1	100	3	0	0	12
12 (Jan 20)	1	1	100	2	2	100	5
13 (Jan 20)	1	1	100	2	0	0	13
14 (Jan 22)	1	1	100	0	0	-	14
15 (Jan 27)	1	1	100	0	0	-	3
16 (Jan 27)	1	1	100	2	0	0	15
17 (Jan 29)	1	1	100	1	0	0	16
18 (Jan 29)	1	1	100	0	0	-	20
19 (Jan 31)	1	1	100	0	0	-	17
20 (Feb 2)	1	1	100	0	0	-	4
21 (Feb 3)	1	1	100	9	0	0	18
22 (Feb 10)	1	1	100	1	0	0	18
23 (Feb 12/13)	1	1	100	4	0	0	19
24 (Feb 17/18)	1	1	100	4	0	0	18

However, during some observation sessions such as Dec 8 and Dec 10, there was no observed hand washing opportunity at a wired sink. Thus it was not possible to calculate *DS_Nurse* for

those sessions, as the denominator would be zero. These sessions were therefore deleted, leading to Table 4.6.

Table 4.6: Event Detections for Observer and Nurses – Sessions with Detection Opportunities

Observation Session	Observer Pre-Test			Nurse Scores			Nurse
	Opportunities	Detected	*DS_Observer*	Opportunities	Detected	*DS_Nurse*	
3 (Jan 5)	1	1	100	2	2	100	6
4 (Jan 6)	1	1	100	2	2	100	7
5 (Jan 8)	1	1	100	1	0	0	8
6 (Jan 10)	1	1	100	2	0	0	9
8 (Jan 12)	1	1	100	1	1	100	11
10 (Jan 16)	1	1	100	4	0	0	12
11 (Jan 17)	1	1	100	3	0	0	12
12 (Jan 20)	1	1	100	2	2	100	5
13 (Jan 20)	1	1	100	2	0	0	13
16 (Jan 27)	1	1	100	2	0	0	15
17 (Jan 29)	1	1	100	1	0	0	16
21 (Feb 3)	1	1	100	9	0	0	18
22 (Feb 10)	1	1	100	1	0	0	18
23 (Feb 12/13)	1	1	100	4	0	0	19
24 (Feb 17/18)	1	1	100	4	0	0	18

Of the 15 remaining observation sessions shown in Table 4.6, the pre-test period still had 100% event detection for the observer for all the observation sessions. Thus, *DS_Observer* was 100% for each of the sessions. But there was 100% detection for *DS_Nurse* during four observation sessions and none during the rest. Thus, comparing the scores between *DS_Observer* and *DS_Nurse* over the 15 observation sessions,

Test-Retest Reliability = 4/15 = 26.7% or 0.266 [0.109, 0.520].

4.4.3 Sink Utilization

Forty of the 47 hand washing events were performed at wired sinks. Wired sink utilization was therefore 40/47 = 85%.

Of these 47 hand-washing events, 37 (that is 16 + 11 + 10) were performed at the three corridor sinks. Therefore the ratio Corridor Sink Utilization: Room Sink Utilization was 78.7% : 21.3%.

SUB-STUDY 2

CHAPTER FIVE

METHODOLOGY

5.1 Introduction

The objective of sub-study 2 was to answer two research questions. The first question was to investigate whether hand hygiene compliance by nurses in the healthcare setting increases with perceived level of infectious risk associated with the nurse-patient interaction. The second question was to investigate whether the duration of nurses' hand hygiene events increase with perceived level of infectious risk associated with the nurse-patient interaction. This objective was to be achieved by testing two null hypotheses which were derived from the questions. Null hypothesis 1, H_{o1}, for the first research question stated that nurses' hand hygiene compliance is not higher for perceived high infectious risk associated with the nurse-patient interaction than for perceived low infectious risk. The second null hypothesis, H_{o2}, for the second question stated that nurses' hand hygiene duration is not longer for perceived high infectious risk associated with the nurse-patient interaction than for perceived low infectious risk.

The methodology that was used in this sub-study is described in this chapter. This includes the study design, data collection and management, analysis and statistical tests used to test the null hypotheses.

5.2 METHODS

5.2.1 Study Design

This was an observational study.

5.2.2 Study Population

The population for this study was all the 85 registered nurses who worked on the unit. Of these, 53 worked full-time and 32 worked as casuals.

5.2.3 Perceived Risk Factor (PRF)

Based on Research Questions 1 and 2, and World Health Organization's *My Five Moments for Hand Hygiene* (Figure 2.1), a summary of all possible nurse-patient interactions on the unit was made.

With the knowledge that self-preservation has been identified as healthcare workers' main motivator for performing hand hygiene (68, 87), any procedure which would entail potential exposure to a patient's body fluids, gross contamination or exposure to an isolated patient was considered to constitute a high risk to the nurse. Also, any procedure which involves access to a sterile body site requires sterile technique; and hand hygiene is an integral part of sterile technique. Thus, it was hypothesized that the nurse would perceive any of these as high risk encounters. These were therefore coded as Perceived High Risk Factors 1 to 5, that is, PRF-H1 to 5, (Figure 5.1). The remaining encounters were classified as Perceived Low Risk Factors, that is, PRF-L1 to 3. The number assigned to the PRF did not have any bearing on severity of the perception as there was no evidence available to justify such grading.

5.2.4 Sample Design and Data Collection

All data that were used in sub-study 2 were collected in sub-study 1. Sample design and data collection have been described in Methodology in Chapter 3. However, two additional columns in the data-collection worksheet (Figure 3.3) were exclusively used in sub-study 2. During the observation, the perceived risk factor (PRF) associated with the hand hygiene opportunity was also recorded. Also recorded was whether or not gloves had been used during the nurse-patient interaction. When collecting data, the observer always had a copy of the PRF chart (Fig 5.1) as a ready reference. All the other entries into the worksheet were as described under Methodology in Chapter 3.

5.2.5 Data Management

Collected data were reviewed for accuracy then entered into STATA IC 10 statistical software for analysis.

Fig. 5.1: Perceived Risk Factors Associated with Patient HCW Interaction

High Risk:		**Code**
• **BEFORE** aseptic task	(Aseptic Technique)	H1
• **AFTER** exposure to body fluids	(Body Fluids)	H2
○ [Suctioning, Blood and blood products administration, Starting IVs, Nausea and Vomiting, Bathing patient, Wound Dressing change, Toileting patient, Catheter insertion, removal or output measuring]		
• **AFTER** handling heavy contamination e.g. garbage cans, shoes, mops, the floor etc	(Patient Contact)	H3
• **AFTER** contact with isolated patient or his environment	(Isolation Status)	H4
• **AFTER** violating aseptic technique	(Aseptic Technique)	H5
Low Risk:		
• **BEFORE** contact with patient or pt environment	(Isolation Status / Patient Contact)	L1
• **AFTER** patient contact but without exposure to body fluids	(Body Fluids)	L2
• **AFTER** contact with non-isolated patient's environment	(Isolation Status)	L3

Key words: Task, Isolation Status and Type, Gloves

5.3 ANALYSIS

This sub-study was independent of RFID/Exciter system. Thus data collected during both the Trial and Study periods were included in the analysis.

5.3.1 Hand Hygiene Compliance

HH Compliance = [No. of times HH was performed] / [No. of HH opportunities]

This fraction was calculated to 95% confidence interval using the formula

$$p \pm 1.96^* \sqrt{p(1-p)/n}$$

Where p = HH Compliance and n = No. of HH opportunities,

Compliance was calculated for each individual nurse as well as for the whole group. This was also done for each perceived risk factor, including aggregated high risk and aggregated low risk factors. Other variations of interest for which hand hygiene compliance was calculated included after glove use, before glove use, after exposure to isolated patients and overall compliance during the three shifts.

Both individual and overall hand hygiene compliance were further subdivided into hand washing compliance and compliance using alcohol hand-rub. A 2X2 contingency table for hand hygiene performance for Aggregated Perceived High and Perceived Low Risk Factors was then generated. This representation is shown in Table 5.1.

Table 5.1: Hand Hygiene Performance for High and Low Perceived Risk Factors

		Hand Hygiene Performed	
		No	**Yes**
Aggregated Perceived Risk Factor	**Low**	A	B
	High	C	D

The Odds Ratio was then calculated and the chi squared test used to determine the significance of the findings. This p-value was used to determine whether to reject or not reject Null Hypothesis 1.

5.3.2 Hand Hygiene Duration

Durations for hand washing and for use of alcohol hand-rub were observed and recorded for three categories: The individual nurse, overall for all nurses and for each Perceived Risk Factor. This duration was calculated to 95% confidence interval.

Hand washing duration to 95% CI = m ± 1.96* $\frac{s}{\sqrt{n}}$

Where *m* is the mean of the hand washing duration for the nurse, *n* is the number of observed hand washing events for the nurse and *s* is its standard deviation for this duration. The same calculation was performed for alcohol hand-rub duration.

A frequency distribution chart for hand washing duration for Aggregated Perceived Low and Perceived High Risk Factors was generated. This distribution was then dichotomized into Short and Long durations. A 2X2 contingency table for hand washing performance for Aggregated Perceived Low and Aggregated Perceived High Risk Factors was then made. Table 5.2 shows this representation.

Table 5.2 Hand washing Duration for Low and High Perceived Risk Factors

		Hand Washing Duration	
		Short	**Long**
Aggregated Perceived Risk Factor	**Low**	A	B
	High	C	D

The Odds Ratio was calculated and chi squared test was used to determine the significance of the findings. This p-value was then used to determine whether to reject or not reject Null Hypothesis 2.

CHAPTER SIX

RESULTS

6.1 Introduction

In this chapter, results from sub-study 2 are described. These results are then analyzed using techniques and tests described under Methodology.

6.2 Observations

Four nurses were observed twice and one nurse three times. The rest were each observed once. Table 6.1 gives a summary of these observations.

Table 6.1: Summary of all Nurses Observed

Variable	Count
Number of nurses observed	20
Number of repeat nurses	(X2, four nurses); (X3, one nurse)
Number of hand hygiene opportunities	390
Hand hygiene opportunities utilized (hand washing + alcohol hand-rub use)	(57 + 103) = 160

6.3 Hand Hygiene Compliance

6.3.1 Overall Hand Hygiene Compliance

Table 6.2 shows the aggregated hand hygiene compliance summary for hand washing and alcohol hand-rub use. Overall compliance was about 41% and compliance by alcohol hand-rub is approximately double that by hand washing.

Table 6.2: Overall Hand Hygiene Compliance

Description	Compliance Rate (95% CI)
Overall compliance (washing and alcohol hand-rub)	0.410 [0.363, 0.460]
Hand washing	0.146 [0.115, 0.185]
Alcohol hand-rub	0.264 [0.223, 0.310]

6.3.2 Nurse-Specific Hand Hygiene Compliance

Table 6.3 gives a breakdown of every individual nurse's hand hygiene compliance rates. These were the overall rate, hand washing rate, alcohol hand-rub rate as well as the ratio between hand washing and alcohol hand-rub rates. As some nurses had very few hand washing or alcohol hand-rub events, breaking each nurse's overall compliance rate to the two components led to very wide confidence intervals in such cases.

Table 6.3: Nurse-Specific Hand Hygiene Compliance (95% CI)

Nurse ID	Overall Compliance	AHR Compliance	HW Compliance	AHR:HW (%)
1	0.417 [0.193, 0.681]	0.250 [0.083, 0.539]	0.167 [0.035, 0.460]	60:40
2	0.391 [0.221, 0.593]	0.044 [0.000, 0.227]	0.348 [0.187, 0.552]	11:89
3	0.310 [0.206, 0.439]	0.310 [0.206, 0.439]	0	100:0
4	0.613 [0.438, 0.763]	0.613 [0.438, 0.763]	0	100:0
5	0.444 [0.276, 0.627]	0.370 [0.215, 0.558]	0.074 [0.010, 0.245]	83:17
6	0.375 [0.135, 0.696]	0.125 [0.001, 0.492]	0.250 [0.063, 0.559]	33:67
7	0.273 [0.092, 0.571]	0.091 [0.000, 0.399]	0.182 [0.040, 0.489]	33:67
8	0.407 [0.245, 0.593]	0.333 [0.185, 0.523]	0.074 [0.010, 0.245]	82:18
9	0.333 [0.150, 0.585]	0.067 [0.000, 0.318]	0.267 [0.105, 0.524]	20:80
10	0.364 [0.150, 0.649]	0.364 [0.150, 0.649]	0	100:0
11	0.200 [0.063, 0.460]	0.067 [0.000, 0.318]	0.133 [0.025, 0.391]	33:67
12	0.435 [0.256, 0.632]	0.130 [0.037, 0.330]	0.304 [0.154, 0.511]	30:70

Nurse ID	Overall Compliance	AHR Compliance	HW Compliance	AHR:HW (%)
13	0.471 [0.262, 0.690]	0.177 [0.054, 0.418]	0.294 [0.130, 0.534]	37:63
14	0.444 [0.188, 0.734]	0.444 [0.188, 0.734]	0	100:0
15	0.286 [0.076, 0.648]	0	0.286 [0.076, 0.648]	0:100
16	0.500 [0.237, 0.763]	0.400 [0.167, 0.688]	0.100 [0.000, 0.426]	80:20
17	0.333 [0.093, 0.704]	0.333 [0.093, 0.704]	0	100:0
18	0.577 [0.442, 0.701]	0.308 [0.199, 0.443]	0.270 [0.167, 0.404]	53:47
19	0.222 [0.085, 0.458]	0	0.222 [0.085, 0.458]	0:100
20	0.300 [0.103, 0.608]	0.300 [0.103, 0.608]	0	100:0

6.3.3 Perceived Risk Factor (PRF)-Based Hand Hygiene Compliance

Hand hygiene compliance rates for the different Perceived Risk Factors are summarized in Table 6.4. There were no observations made for Perceived High Risk Factor 5, and only three observations were made for Perceived High Risk Factor 1. For these PRFs, no hand hygiene was performed, and thus the compliance was zero.

Table 6.4: Perceived Risk Factor (PRF)-based Hand Hygiene Compliance

Perceived Risk	Overall Compliance (95% CI)
Aggregated Perceived Low Risk Factor	0.282 [0.233, 0.337]
Aggregated Perceived High Risk Factor	0.745 [0.654, 0.819]
Perceived Low Risk 1 (Before Contact with Patient or Patient Environment)	0.106 [0.069, 0.159]
Perceived Low Risk 2 (After Patient Contact but without Exposure to Body Fluids)	0.692 [0.583, 0.784]
Perceived Low Risk 3 (After Contact with Non-Isolated Patient's Environment)	0.294 [0.130, 0.534]
Perceived High Risk 1 (Before Aseptic Task)	0
Perceived High Risk 2 (After Exposure to Body Fluids)	0.750 [0.528, 0.892]
Perceived High Risk 3 (After Handling Heavy Contamination, e.g. garbage can, mop, shoes)	0.286 [0.076, 0.648]
Perceived High Risk Factor 4 (After Contact with Isolated Patient or his Environment)	0.816 [0.713, 0.888]
Perceived High Risk Factor 5 (After violating Aseptic Technique)	-

6.3.4 Effect of Gloves

Results in Table 6.5 show that hand hygiene compliance after glove use was ten times that before glove use. There was no significant change in this ratio, even when patients were separated into isolated and non-isolated cases.

Table 6.5: Effect of Gloves

Glove Use	Compliance (95% CI)
Hand Hygiene before glove use	0.081 [0.035, 0.169]
Hand Hygiene after glove use (Total)	0.802 [0.708, 0.872]
Hand Hygiene after Glove use for isolated patients	0.825 [0.726, 0.894]
Hand Hygiene after glove use for non-isolated patients	0.778 [0.443, 0.947]

Glove use in relation to Perceived Risk Factor was also a quantity of interest. Table 6.6 shows the frequency of glove use for the different Perceived Risk Factors. *Before Patient Contact* had the highest number of instances when gloves were used. This was closely followed by *After Contact with Isolated Patient or his Environment*, and *After Exposure to Body Fluids*. However, there were instances when gloves were required to be used but were not used. These include *Before Aseptic Task* and *After Exposure to Body Fluids*.

Table 6.6: Frequency of Glove use for Different Perceived Risk Factors

Perceived Risk Factor	Gloves Worn	Gloves Not Worn
Perceived Low Risk 1 (Before Contact with Patient or Patient Environment)	74	114
Perceived Low Risk 2 (After Patient Contact but without Exposure to Body Fluids)	4	74
Perceived Low Risk 3 (After Contact with Non-Isolated Patient's Environment)	-	17
Perceived High Risk 1 (Before Aseptic Task)	2	1
Perceived High Risk 2 (After Exposure to Body Fluids)	17	3
Perceived High Risk 3 (After Handling Heavy Contamination, e.g. garbage can, mop, shoes)	7	-
Perceived High Risk Factor 4 (After Contact with Isolated Patient or his Environment)	61	15

6.3.5 Shift-Based Hand Hygiene Compliance

Table 6.7 shows hand hygiene compliance stratified on the basis of shifts.

Table 6.7: Shift-Based Compliance

Shift	Compliance (95% CI)
Day	0.467 [0.400, 0.534]
Evening	0.326 [0.255, 0.407]
Night	0.389 [0.248, 0.552]

There was a clear graduation in shift-specific compliance with Day>Night>Evening.

6.4 Hand Hygiene Duration

Results for hand hygiene duration for each nurse are shown in Table 6.8; and those for Perceived Risk Factors are recorded in Table 6.9. For the individual nurses, some observations were so few that some had very wide confidence intervals extending into negative values.

Nurse 5, for example had a hand washing duration of 7.5 [-24.3$^{\xi}$, 39.3] seconds. Such negative times were noted as not being meaningful.

Table 6.8: Hand Hygiene Duration for Individual Nurse (95% CI)

Nurse ID	Observed Alcohol Hand-Rub Duration (seconds)	Observed Hand Washing Duration (seconds)
1	3.3 [-2.4$^{\xi}$, 9.1]	3
2	3	2.6 [1.9, 3.4]
3	6.2 [5.0, 7.4]	0
4	5.5 [4.6, 6.5]	0
5	5.4 [4.1, 6.7]	7.5 [-24.3$^{\xi}$, 39.3]
6	2	4.5 [-1.9$^{\xi}$, 10.9]
7	3	2
8	4.6 [3.5, 5.6]	6.5 [-50.7$^{\xi}$, 63.7]
9	2	10 [0.9, 19.1]
10	2.8 [2.0, 3.5]	0
11	6	4 [-8.7$^{\xi}$, 16.7]
12	4.3 [0.5, 8.1]	9.4 [5.9, 13.0]
13	2.7 [1.2, 4.1]	8.2 [3.9, 12.5]
14	3.5 [2.6, 4.4]	0
15	0	7
16	3.3 [2.5, 4.0]	4
17	5.5 [-26.3$^{\xi}$, 37.3]	0
18	3.6 [3.1, 4.0]	4.1[3.5, 4.8]
19	0	3.3[2.5, 4.0]
20	5.0 [-1.6$^{\xi}$, 11.6]	0

ξ = Negative time is not meaningful

Table 6.9: Perceived Risk Factor-Specific Hand Hygiene Durations (95% CI)

Perceived Risk Factor	Alcohol hand-rub duration (s)	Hand washing duration (s)
Aggregated Perceived Low Risk Factor	4.5 [4.1, 5.0]	4.3 [3.4, 5.3]
Aggregated Perceived High Risk Factor	4.8 [4.1, 5.4]	6.4 [4.9, 7.9]
Perceived Low Risk 1 (Before Contact with Patient or Patient Environment)	4.3 [3.3, 5.2]	4.5 [2.9, 6.1]
Perceived Low Risk 2 (After Patient Contact but without Exposure to Body Fluids)	4.6 [4.0, 5.2]	4.6 [3.2, 5.9]
Perceived Low Risk 3 (After Contact with Non-Isolated Patient's Environment)	4.5 [1.7, 7.3]	2
Perceived High Risk 1 (Before Aseptic Task)	0	0
Perceived High Risk 2 (After Exposure to Body Fluids)	4.7 [2.7, 6.8]	7 [3.2, 10.8]
Perceived High Risk 3 (After Handling Heavy Contamination, e.g. garbage can, mop, shoes)	2	10
Perceived High Risk Factor 4 (After Contact with Isolated Patient or his Environment)	4.9 [4.1, 5.6]	6.0 [4.2, 7.9]
Perceived High Risk Factor 5 (After violating Aseptic Technique)	-	-

6.5 ANALYSIS

6.5.1 Hand Hygiene Compliance

Table 6.10: Hand Hygiene Performance vs. Aggregated Perceived Risk Factors

		Hand Hygiene Performed	
		No	**Yes**
Aggregated Perceived Risk Factor	**Low**	203	81
	High	27	79

Table 6.10 shows the 2X2 contingency distribution for hand hygiene performance for the aggregated high and low perceived risk factors.

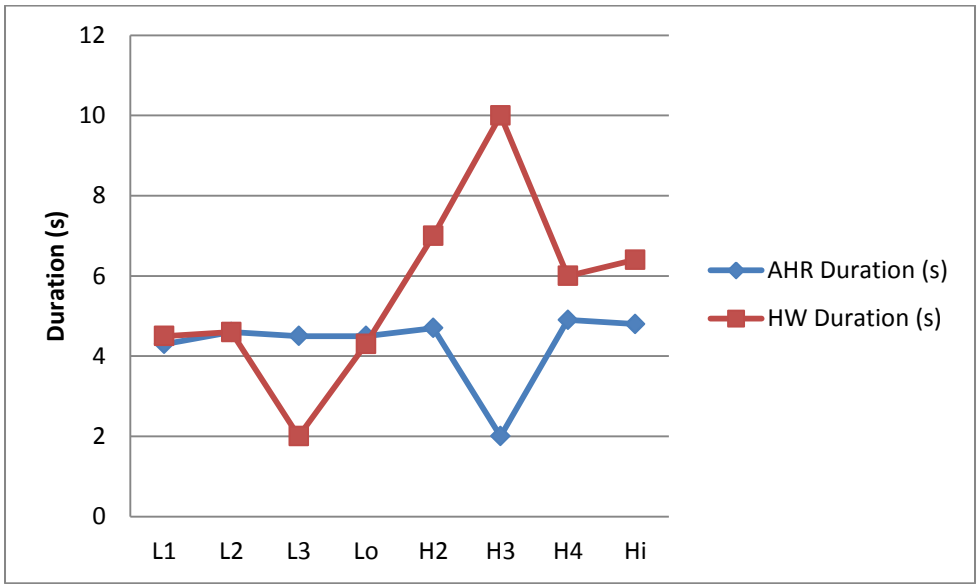
Odds Ratio = 7.33 [4.19, 12.82] to 95% CI, calculated using STATA IC 10 statistical software, both by Fisher's Exact method and Chi Square:

χ square = 67.36, $p<0.0001$.

6.5.2 Hand Hygiene Duration

Perceived High Risk Factor 1 (Before Aseptic Task) had zero compliance therefore zero duration, which is meaningless. No hand hygiene opportunity or event was observed for Perceived High Risk Factor 5 (After violating Aseptic Technique). If these two risk factors are omitted and a plot of hand washing duration and alcohol hand-rub use duration made, the graph looks as shown in figure 6.1.

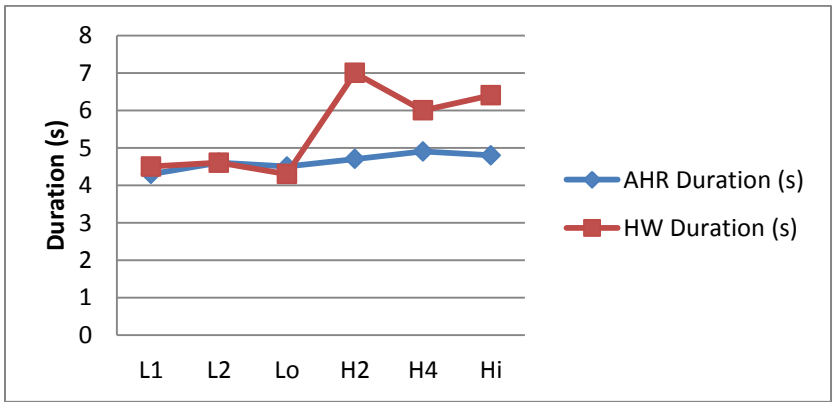
Figure 6.1: Hand Hygiene Durations for Different Perceived Risk Factors (PRFs)



From Figure 6.1 and Table 6.9, it can be seen that hand hygiene duration for alcohol hand-rub use was relatively stable at about 4.5 seconds for all high and low Perceived Risk Factors. For Perceived High Risk Factor 3, *After Handling Heavy Contamination*, it dipped to two seconds. Hand washing had a two-way split across the High – Low Perceived Risk Factor divide. The hand washing event lasted approximately 4.5 seconds or less in the Low Perceived Risk Factors. On Perceived Low Risk 3, *After Contact with Non-Isolated Patient's Environment*, this dropped further to two seconds. On the Perceived High Risk side, the event lasted six seconds or higher, with a peak at Perceived High Risk 3 *After Handling Heavy Contamination*.

But Perceived High Risk Factor 3 (PRF-H3), that is, *After Handling Heavy Contamination* was a single event each for hand washing and use of alcohol hand-rub. Similarly, Perceived Low Risk Factor 3 (PRF-L3) that is, *After Contact with Non-Isolated Patient's Environment* was a single event for hand washing. These three single event observations were therefore unlikely to be accurate representations of hand hygiene duration for their respective perceived risk factors. If they are omitted and the graph re-drawn, it looks as shown in Figure 6.2.

Figure 6.2: Hand Hygiene Durations for Different Perceived Risk Factors (PRFs)



As can be seen from Figure 6.2 and Table 6.11, there was a clear two second difference between hand-washing duration for the Aggregated Perceived Low Risk Factor (Lo) and Aggregated Perceived High Risk Factor (Hi). There was no real difference between the values for alcohol hand-rub use.

Table 6.11: Hand Hygiene Durations for Aggregated Perceived Low and Perceived High Risk Factors [95% CI]

	Hand Washing Duration (seconds)	Alcohol Hand-Rub Duration (seconds)
Aggregated Perceived High Risk Factor	6.4 [4.9, 7.9]	4.8 [4.1, 5.4]
Aggregated Perceived Low Risk Factor	4.3 [3.4, 5.3]	4.5 [4.1, 5.0]

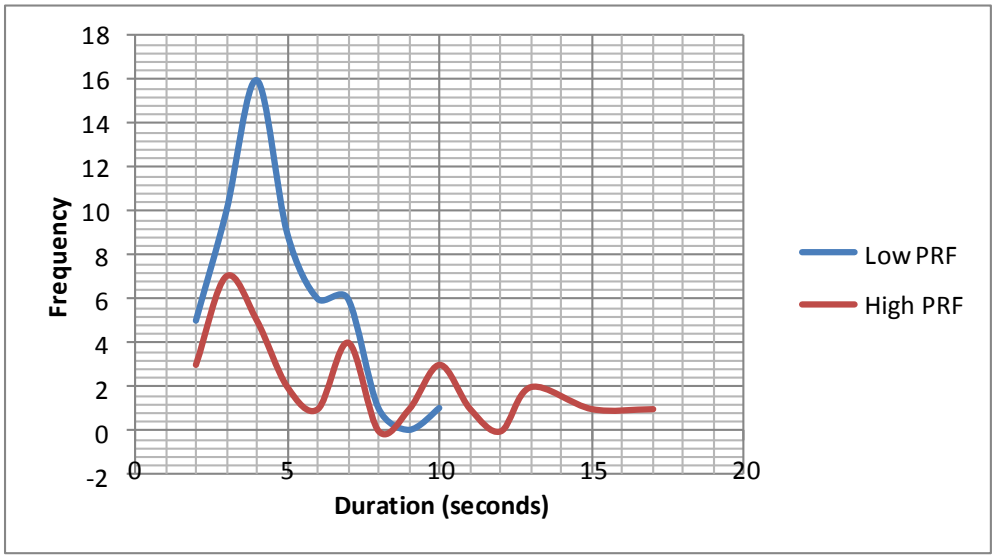
Table 6.12 and Figure 6.3 show the frequency distribution of the durations of hand washing for the aggregated low and high perceived risk factors. From these, a suitable point for dichotomization of hand hygiene duration between 'long' and 'short' was to be determined.

Table 6.12: Frequency Distribution for Aggregated Perceived Low and Perceived High Risk Factors

Hand Washing Duration (sec.)	Aggregated Perceived Low Risk Factor	Aggregated Perceived High Risk Factor
2	5	3
3	10	7
4	16	5
5	9	2
6	6	1
7	6	4
8	1	-
9	-	1
10	1	3
11	-	1
12	-	-

Hand Washing Duration (sec.)	Aggregated Perceived Low Risk Factor	Aggregated Perceived High Risk Factor
13	-	2
15	-	1
17	-	1

Figure 6.3: Frequency Distribution for Aggregated Perceived Low and Perceived High Risk Factors



For the Aggregated Perceived High Risk Factor, 3 seconds was considered the point at which distribution could be dichotomized into long and short hand washing duration. For the Aggregated Low Perceived Risk Factor, this point was at about 4 seconds. Owing to the higher frequency for the Aggregated Perceived Low Risk Factors, that is, 16 at duration of 4 seconds, dichotomization was made at 4 seconds. Hand washing for 4 seconds or less was considered short hand washing duration and anything above that was long hand washing duration.

Table 6.13 shows a 2X2 contingency representation for hand washing for these aggregated perceived risk factors after dichotomization of hand washing duration.

Table 6.13: Aggregated Perceived Low and High Risk Factors vs. Hand washing Duration

		Hand Washing Duration	
		Short	**Long**
Aggregated Perceived Risk Factor	**Low**	275	9
	High	90	16

Odds Ratio = 5.43 [2.27, 12.00] to 95% CI, calculated using STATA IC version 10 software, both by Fisher's Exact method and Chi Square: χ square = 18.25, $p<0.0001$.

SUB-STUDY 3

CHAPTER SEVEN

METHODOLOGY

7.1 Introduction

In this section, the methodology used in sub-study 3 as well as the rationale for its selection are discussed. Also discussed are the study methods, including the sampling process, data collection and analysis.

7.2 METHODS

Sub-study 3 was a qualitative study using the Grounded Theory methodology. The application of this methodology in this sub-study is described in the *Data Collection* section. The objective of sub-study 3 was to investigate the determinants of hand hygiene practice and explore social and behavioral aspects of hand hygiene practice in the healthcare setting. Thus, collecting data from interviews, analyzing the data and making general conclusions was considered an ideal way to achieve this.

7.2.1 Sample Design and Selection

Sampling was done in two stages. In the first stage, the objective was to select participants to be interviewed. During this stage, six participants from the 20 who had participated in Sub-Study 1 were to be selected for face-to-face interviews on their hand hygiene practice. These participants' hand hygiene practices were to be as representative of the hand hygiene practice spectrum on the unit as possible.

Several challenges to selecting a representative sample were identified. The pool from which participants were to be selected was already narrow, that is, the 20 nurses who had participated in sub-studies 1 and 2. Also, although in these two sub-studies, measures had

been put in place to minimize selection bias, the 20 nurses had been selected by convenience. Thus the degree to which their hand hygiene practices were representative of the practices on the unit was unknown. In addition, at the end of every observation session in sub-study 1, the observer had informed the participant that an interview would be following at a future date. Although all 20 had stated they would consent to this follow-up interview, possible declines, non-responses and unreachable invites would have to be taken into consideration.

Another challenge was in relation to the actual practice of hand hygiene. Hand hygiene practice is inherently a complex undertaking (29, 92). In addition to being as varied as the individuals, there are also preferences and decision-making processes for or against hand washing and/or use of alcohol hand-rub. This means that a truly representative sample would have to be the entire nursing population on the unit.

To address these challenges sampling for this sub-study was based on key important variables that were thought to serve theory development. Hand hygiene elements of interest were identified and used in selection of the most suitable participants to be invited for interview. The highest and lowest overall hand hygiene compliance rates were identified as elements of interest. Similarly, nurses who had demonstrated preference for hand washing over use of alcohol hand-rub and vice versa were also to be selected. Longest and shortest duration for hand washing and for use of alcohol hand-rub were also identified as characteristics of interest. And finally, any unusual or unexpected hand hygiene practices were also to be captured. In one such unusual behavior, a nurse had been observed to consistently follow hand washing with use of alcohol hand-rub in sub-studies 1 and 2. These sub-studies were conducted before sub-

study 3. Therefore preliminary results from them were used during this sample selection process.

It was estimated that interviews with up to six nurses would generate sufficient data to inform theory development and answer the research question of the sub-study. This strategy, which aimed at maximizing the number of elements of interest in as few, potentially prime participants as possible offered an additional challenge.

To address this challenge, the two best participants under each element of interest were identified. For example, the two participants with the shortest hand washing duration were selected under the element of interest: Shortest Hand Washing Duration." The second participant was a back-up participant in case the leading participant was either unreachable or declined to be interviewed. Where possible, participants with the best scores, but with wide confidence intervals were not considered for invitation. This was because wide confidence intervals were considered to be an indication that the number of observations leading to that score was too small. The figure was therefore not an accurate representation of that element of interest. Some participants, such as Nurse 4 and Nurse 13, qualified in multiple categories, and were thus prime potential interviewees. These prime participants were selected as the primary invites in only one category each, and acted as back-up for the other categories in which they qualified.

Standard but personalized invitation letters were then sent to the 12 selected participants, inviting them for individual 30-minute interviews at times and locations that were convenient for them. Follow-up letters were sent out two weeks later those who did not respond. And two weeks after that, a final reminder phone call or face-to-face request on the unit on the unit

where possible were made. Tables 7.1 to 7.4 show participants who were identified as most qualified under the different elements of interest.

Table 7.1: Element of Interest – Hand Hygiene Compliance

	Characteristic	Nurse ID	Compliance (95% CI)
1.	Highest overall compliance	18	0.577 [0.442, 0.701]
		4	0.613 [0.438, 0.763]
2.	Lowest overall compliance	7	0.273 [0.092, 0.571]
		11	0200 [0.063, 0.460]
		19	0.222 [0.085, 0.458]
		3	0.310 [0.206, 0.439]

Table 7.2: Element of Interest – Hand Hygiene Preferred Method

	Characteristic	Nurse ID	AHR : Hand Washing Ratio
1.	Alcohol hand-rub preference over hand washing	4	100% : 0 (19 AHR: 0 HW Events)
		1	60% : 40% (3 AHR : 2 HW Events)
2.	Hand washing preference over alcohol hand-rub	2	11% : 89% (1 AHR : 8 HW Events)
		13	37% : 63% (3 AHR : 5 HW Events)

Table 7.3: Element of Interest – Unusual Hand Hygiene Practice

	Characteristic	Nurse ID	Unusual Practice
1.	Unusual hand hygiene practice	18	Uses AHR followed by HW
		9	Uses AHR followed by HW

Table 7.4: Element of Interest – Hand Hygiene Duration

	Characteristic	Nurse ID	Duration (seconds); 95% CI
1.	Longest hand washing duration with good hand washing compliance	12	9.4 [5.9, 13.0] (HW Compliance = 0.304 [0.154, 0.511])
		13	8.2 [3.9, 12.5] (HW Compliance = 0.294 [0.130, 0.534])
	Characteristic	**Nurse ID**	**Duration (seconds); 95% CI**
2.	Shortest duration for hand washing with many opportunities and good hand washing compliance	2	2.6 [1.9, 3.4] (23 HH Opportunities) (HW Compliance = 0.348 [0.187, 0.552])
3.	Longest duration for AHR use with many opportunities and good AHR compliance	4	5.5 [4.6, 6.5] (31 HH Opportunities) (AHR Compliance = 0.613 [0.438, 0.763])
		8	4.6 [3.5, 5.6] (27 HH Opportunities) (AHR Compliance = 0.333 [0.185, 0.523])
4.	Shortest duration for alcohol hand-rub use and good AHR compliance.	10	2.8 [2.0, 3.5] (11 HH Opportunities) (AHR Compliance = 0.364 [0.150, 0.649])
		13	2.7 [1.2, 4.1] (17 HH Opportunities) (AHR Compliance = 0.177 [0.054, 0.418])

HW = Hand Washing HH = Hand Hygiene AHR = Alcohol Hand-Rub

7.2.2 Responses

Of these 12 selected potential participants, two nurses no longer worked on the unit and were unreachable. One nurse declined to be interviewed. Four nurses never responded, despite follow-ups. A total of five nurses accepted the invitation and were successfully interviewed. These were Nurses 1, 7, 11, 12 and 18.

The second stage of sampling employed the *theoretical sampling* (112-122) technique of Grounded Theory methodology. This process is described under *Data Collection and Analysis*.

7.2.3 Data Collection and Analysis

At the start of the interview session, the participant was offered a consent form (Appendix C), given time to read it and offered a chance to ask any questions before signing it. This form was the same one that had been used in sub-studies 1 and 2, but with minor modifications to reflect the requirements of the current sub-study. As was the case during the first two sub-studies, the interviewer kept the original signed form but gave the participant a photocopy for their record.

Interviews, lasting up to 30 minutes, were conducted and audio-recorded at a time and venue that were convenient to the participant. Appendix D shows the primary questions which were asked during the interviews. Secondary probing questions were asked if further clarification was needed; or when an answer gave insight into a new, unexplored new area.

Data collection and analysis were iterative and informed each other. Thus, after interview with a participant, the audio-recorded interview was manually transcribed and at least partially analyzed before the next interview. Emerging patterns from the analysis helped the interviewer to identify which questions to concentrate on and also where there might be gaps in the

emerging theory. Thus, the emerging theory was progressively built using data from every subsequent interview.

The process of analysis was also performed manually. From the data, specific concepts were identified. Related concepts were grouped together into categories (112-122). With every subsequent interview, concepts which kept recurring strengthened the categories to which they belonged, thus cementing the importance and relevance of those categories in the emerging theory. This emerging theory was continuously back-referenced to the data to check its grounding (112-122).

Saturation point was considered to have been achieved when there were no more new concepts or ideas emerging from the interviews (112-122). A saturated category was considered to be a sign that sufficient data for formulation of the theory had been collected (112, 113). Also, because of the constant back-checking, saturation was an indication that the data was consistent and therefore the emerging theory was more likely to have strong grounding in the data (112-114).

Links between categories were identified. Categories which fit together were grouped together and linked to explain the wider evolving theory. Greater focus was on these stronger categories as weaker categories were relegated to the periphery and even discarded. The justification for this discarding of weak categories was that as an inductive model, Grounded Theory is primarily focuses on the strength of relationships (114, 115). The strength of a category was determined by how important participants perceived its concepts to be; as well as how often the category appeared in the interview. Thus, a concept described as “very important,” “fundamental” or “key” contributed to the importance and centrality of the category to which it belonged.

Categories and groups of categories which had high perceived importance and/or appeared frequently were considered to be strong in the emerging theory. The category which was identified as most important and appeared at a high frequency was designated as the central category (117, 119, 120). This category became the key category around which the emerging theory was built.

Relationships between the categories were represented using causal network format (115). This model is a "visual rendering of the most important independent and dependent variables in a field study, and the relationship between them (p.132)." This representation was chosen because of its simplicity and its directional, causal nature. It was therefore felt that the model would be ideal for meeting the objectives of this sub study, that is, to explore social and behavioral factors which influence nurses' hand hygiene practice in the healthcare setting.

7.2.4 Bias-Limiting Strategies

Several strategies were used to ensure soundness of methodology and to keep the researcher's personal biases to a minimum in the emerging theory. The first strategy was the technique of continuous back-checking of grounding of the theory against the data. This technique is inherent in Grounded Theory methodology and helps to ensure that the theory is an accurate product of the data. Another strategy was to discuss the methodology with one member of the committee in order to identify potential weaknesses in study design and possible areas of bias. Participant selection process also helped to minimize selection bias. Selecting participants to be invited based purely on their results in sub-studies 1 and 2 ensured that any potential preferences by the interviewer were kept to a minimum.

CHAPTER EIGHT
RESULTS

8.1 Introduction

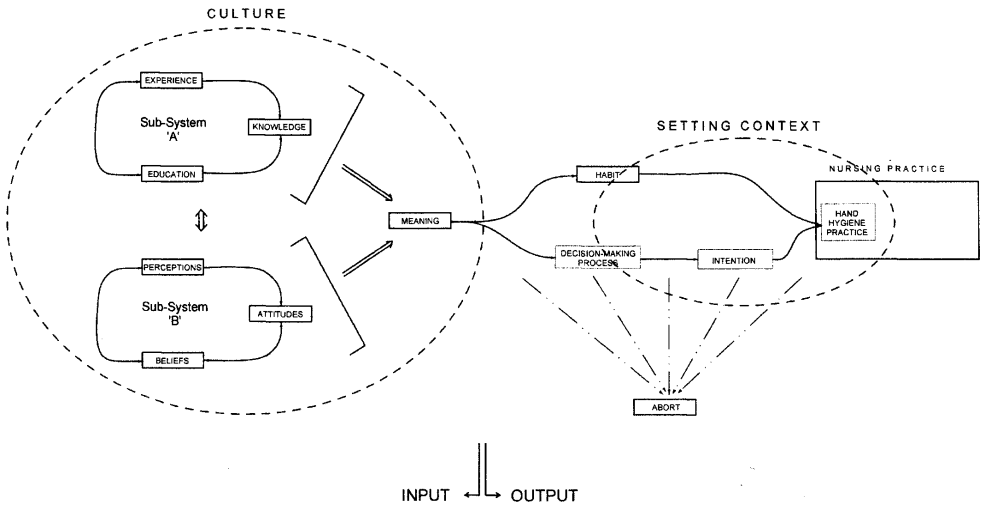
In this chapter, results from the interviews and analysis are discussed. The emerging relationships between the different behavioral and social categories are also discussed. The effect of these different categories on hand hygiene practice is explored.

8.2 Hand Hygiene Relationships

Results from the interviews and analysis revealed a number of categories which were identified as having influence on the nurses' hand hygiene practice. Appendix E is a tabulation showing how Concepts were generated from answers; and how these Concepts were then grouped together into categories. The emerging theory was frequently back-checked against the data to ensure grounding.

Relationships between categories with directional representation were identified where possible. Some of these categories are internal to the nurse while others originate from social influences, both at work and at home. The categories were further clustered into related groups which form interacting sub-systems. These sub-systems influence the nurse's hand hygiene practice. These relationships, which were presented in a causal network format, are illustrated in Figure 8.1. This entire system of relationships can be split into two sections: Input Side and Output Side.

HAND HYGIENE RELATIONSHIPS



8.2.1 Input Side

The input side is essentially associations and relationships that are already in place and are used every time the nurse is to perform a hand hygiene act. The category called *Meaning* of hand hygiene emerged as the central category upon which hand hygiene practice hinges. What hand hygiene means to the nurse ultimately has strong bearing on her hand hygiene practice. The centrality of *Meaning* is evident in participants' answers to the question: "What does hand hygiene mean to you?"

Nurse 1 Ans 1 Well (pause) it's um a baseline for nursing and it means prevent, prevention, protection um (pause) reduction of infectious diseases. It's you know (pause) um it's just basic (pause) nursing um what's the word that I'm looking for? (pause) It's just so important. The basis of all our care is, that's where you start, to, to reduce infections, to prevent infections, to anything like that. So, it's very important.

and

Nurse 11 Ans 11 OK. Very important. To, maintain hand hygiene. Ahh, very important to, prevent infection, especially in the hospital. Good proper hand hygiene is, is ahh, I think we underestimate how important it is so.

Also

Nurse 18 Ans 2/3 Very important. (pause) Um, well 'cause that's infection prevention right? Everything that goes around in the hospital has to do with, you know hand hygiene can (pause) can uh, can prevent that spread of infection.

Nurses' understanding of the importance of hand hygiene was not in question. *Meaning* of hand hygiene also emerged as the final element on the input side before the action side, that is, the output side. That *Meaning* is strategically located between the input and output sides of the relationships, reinforces the centrality of this category to the nurses' overall hand hygiene practice.

And this *Meaning* is fed upstream by a combination of two interacting subsystems, each made up of several distinct but interacting categories. The first sub-system, Subsystem 'A', is a cluster consisting of the categories *Experience, Education* and *Knowledge.* Subsystem 'B' is the cluster made up of *Beliefs, Perceptions and Attitudes*. Both subsystems and their associated elements operate in an atmosphere that is encompassed in the category that was coded *Culture*. And culture is an evolving concept which is itself influenced by the nurse's living and working environment.

Subsystem 'A' emerged as the *Information* cluster while Subsystem 'B' is the cluster that can be considered to be the *Internal Outcome* of this information, that is, the effect of this information on the person. Both subsystems then ultimately result in a *Meaning*, in this case, the meaning of hand hygiene to the individual. Any hand hygiene activity performed will be coming from this meaning.

Subsystem 'A' (Information cluster)

Knowledge

This is informed by *Experience* and both formal and informal *Education.* What the nurse knows about hand hygiene is a building block for what hand hygiene ultimately means to her. The nurses made reference to the importance and impact of in-services and training by Infection

Prevention and Control staff as important in shaping their hand hygiene practice. Strategic location of signage was also quoted as a continuing reminder, which reinforced *Knowledge*. These come in through the *Education* process, and are then internalized as *Knowledge*.

Experience and *Education*

What the nurse has learnt both formally and informally, as well as what she has observed and gone through pertaining to hand hygiene are also building blocks to what hand hygiene means to her. *Experience* was not limited to what the nurse had personally gone through. Rather, this also included what the nurse had observed from other nurses' hand hygiene practice. When asked if she thought hand hygiene was as important to others as it is to her, one nurse replied

Nurse 12 Ans 50-56 (pause) Um, (pause). I think to some it is and some it's not. Not that they don't think it's important, but they, (pause) I don't know. You know just (pause) I just ah this isn't really hand hygiene, but as ah, you know I came on evening shift and with the day nurse, you know we were in the common room, and she wasn't wiping down her stethoscope in between patients. And to me that's just common practice. And she said, 'Oh I didn't even think about that.' So it's not that it wasn't important to her it's just something that she doesn't... incorporate into her practice. On a regular basis. I don't know. And I know that's not hand hygiene but that's you know (pause) maybe an example of (pause) how people might feel about hand hygiene 'cause that's, you know, just the prevention of (pause) the spread of (pause) germs and whatnot.

And both *Experience* and *Education* influence each other. Thus, the sub-system is dynamic, with interacting categories influencing and reinforcing each other.

Nurse 1 Ans 2/3 I've definitely changed my ways after, like, since I've been a nurse, and yeah I'm more diligent about it at home and when I'm in public and, and whatnot, but most, yeah I do practice it the same way. I'm just more, I guess I'm being from nursing, I'm more conscious about it outside now, like, outside of work. And watching other people, I (pause) kinda (pause) shake my head sometimes. (Laugh)

Therefore acquiring hand hygiene education or a new, positive hand hygiene experience leads to improved or better understanding and consequently more knowledge about hand hygiene. This improved knowledge or understanding made the nurse value hand hygiene more, that is, had a positive impact on the category called *Meaning*. Nurse 7 rated her compliance at 95-98%. When asked the secret behind her success, her answer was:

Nurse 7 Ans 53 Um I think th-this environment because we have so many people with these um bugs that are resistant, and w-we have had numerous reminders from Infection Prevention Control. We've had monitoring by the Infection Prevention Control nurses, watching our behaviors. Ahh, we've been reminded of y'know of, by them, of when to wash and how in what way we might be contaminating ourselves or the patients. And I think in general the awareness on our unit is really increased about the importance of hand hygiene. Um, we've been using Microsan for quite a number of years now, um at one point there was a, a competition for

producing a video related to Microsan, so, I've participated in prepar-, ahh, preparing a video that went on YouTube and I was Microsan Mike.

Subsystem 'B' (Effects cluster)

Attitudes, Perceptions and Beliefs

Attitudes towards hand hygiene are informed by how the nurse perceives hand hygiene; and what she believes about it. These attitudes, in turn, have an influence on what the nurse believes about hand hygiene. *Perceptions* and *Beliefs* also influence each other. When asked if she practiced HH the same way all the time, Nurse 7 replied:

Nurse 7 Ans 5 No. I have a work-related kind of awareness about hand hygiene and home-related hand hygiene. They are not the same. Ahh, at work I'm much more attentive to protecting myself and patients with hand hygiene at home I don't worry about it at all. I will go into the garden, I will go into the kitchen, I will wash my hands which have been in the garden in the kitchen. I don't worry about bug transmission at home. Ahh, when I'm in public sometimes I think about it just because of my exposure in the hospital, but I usually don't worry. If I use the facilities in the mall for example, I'll take care to wash my hands and use the Sandy Foam if, if it's there but I don't worry about it too much. Um, the opportunities don't arise that often in public.

In addition to the positive descriptions of hand hygiene such as "Fundamental to Nursing" and "The starting point of all our care," there were some obstacles mentioned. Some barriers such as "Poor water temperature" and "Dysfunctional dispensers" are beyond the nurse's control. However, others like "But no one washes hands for 30 seconds" suggests beliefs, attitudes and

perceptions about the nurse's ability to perform hand hygiene as required. Before successfully performing the hand hygiene action correctly, the nurse needs to have the conviction that she can do it (93, 94, 97). The categories in this cluster therefore emerge as very closely interconnected, and influencing each other.

Culture

Culture emerged as a category within which the entire input side of the relationships operates. This entire side is influenced by the nurse's own culture as well as the prevailing culture at the workplace. Thus, the whole hospital has its own general culture and nested within this are cultures for the individual patient-care units. These local unit cultural influences were evident from Nurse 1's reply regarding what she thought about the use of gloves in relation to hand hygiene.

Nurse 1 A 85 I think people are misled that gloves will protect you from everything that you don't need to wash after. Which (pause) that's, I don't think is appropriate. I think, no matter what that you should be performing the hand hygiene before and after gloving. Um, especially in isolation rooms too. Ahh (pause) I dunno, I just…

And when further probed regarding what might be causing people to be misled in this way, the reply showed that there are links between this culture and the other categories on the Input Side that is, *Education*, *Beliefs*, *Knowledge* and *Experience*.

Nurse 1 A 86 Probably just ahh, (pause) you know people ahh aren't educated as much that you know, like, that it, contaminants can be on the boxes, um there might be a hole in your glove. Like, little things that people just might not, consider. Um,

> back in the days, kinda, before hand hygiene was so emphasized, gloves and all be all right? You put gloves on you're protected. I dunno maybe it's just like, (pause) ahh, missed or how people were educated… Um, I'm not sure what would be to that.

The nurse's culture is forged by her background, including home, family and community. Her hand hygiene culture at work is therefore the result of the influences of all these seed cultures as well as the prevailing culture at the workplace. Statements such as: "I have a work-related and a home-related awareness about hand hygiene" and "I don't worry about bug transmission at home" attest to this. And this resulting culture ultimately has an influence on the meaning of hand hygiene to the nurse. Thus, *Culture* emerged as an important category which influences the whole lead up to hand hygiene practice.

8.2.2 Output Side

The nurse can take one of two possible routes towards hand hygiene performance. She can perform hand hygiene as a *Habit*, without much thought or consideration. Alternatively, the nurse could go through an active *Decision-Making Process.* However, whichever route that is taken will still ultimately, in the background, be determined by the *Meaning* of hand hygiene to the individual. The process leading to a hand hygiene act can *Abort* at any stage of the output side. Any one of many factors can lead to this abortion. Some that were mentioned during the interviews include soap or paper towel dispenser malfunction, wrong water temperature, "can't find a sink", being busy etc.

Habit

When deliberate, conscious decision-making is by-passed, the nurse may perform hand hygiene via the *Habit* route. When this route is taken, the category *Setting Context* becomes less of a factor. But habits do not just form out of nothing. A hand hygiene habit will form based on what hand hygiene means to the individual. This meaning is dynamic and builds over time, based on the previously-mentioned, continuously-evolving upstream subsystems and their integral categories and concepts. When asked how she decides which method to use, Nurse 11 replied

Nurse 11 A70 It's subconscious, totally. I find it subconscious. (Pause) And I know, like whenever I'm about to pour medications, I'll, I'll go to the sink. If I know that I'll be touching medications, (pause) I always wash my hands first.

Decision-Making Process

This is essentially a mental algorithm that the nurse executes once what she perceives as a hand hygiene opportunity presents itself. This process, just like the *Habit* route, may occur within the *Setting Context* or outside of it. However, in most cases, *Setting Context* emerged as an important and necessary consideration in the lead up to a hand hygiene event. This context is defined by such factors as "at home", "at work" and "in public places like malls" etc. For example, participants were of the opinion that hospital, that is, the workplace, is 'dirty' compared to home.

Nurse 7 Ans 6 Mhmm, I-I don't feel that there are bugs in my immediate environment that are a threat to me at home. Um, I know that ahh, y'know if, if you're not wiping every surface down everyday then bacteria will accumulate in different places in

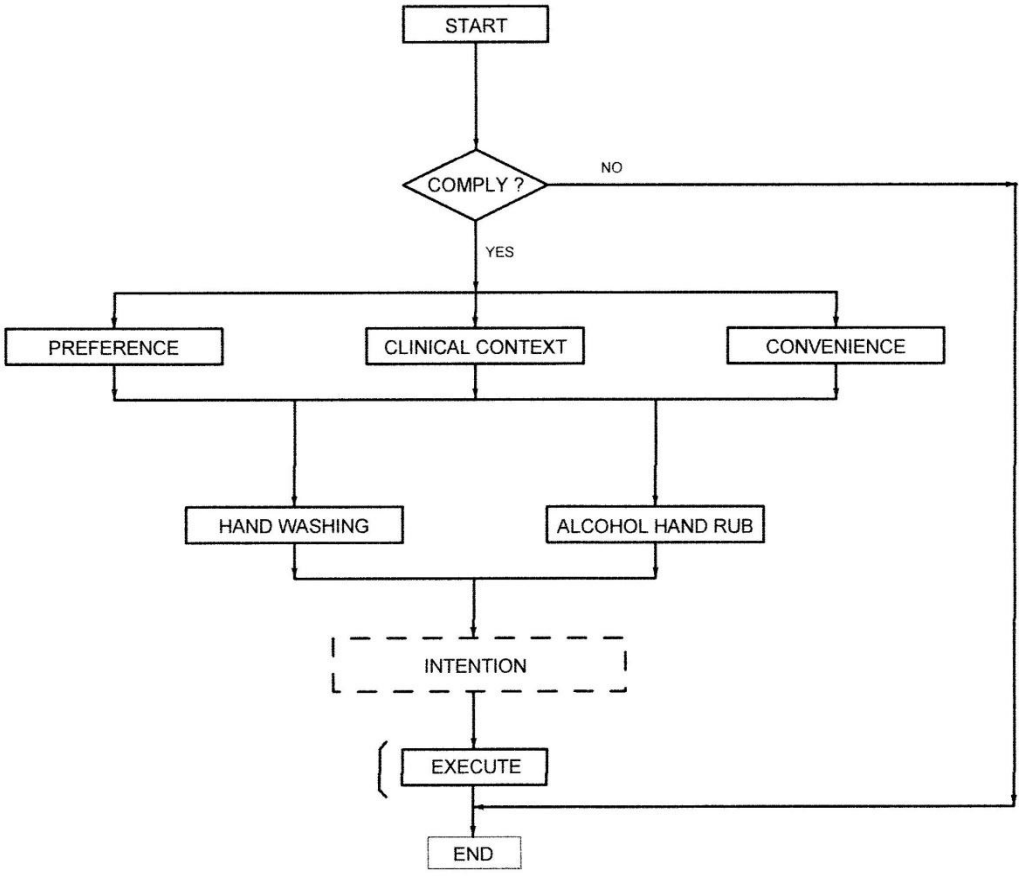
> the house. Whether it's the kitchen, or the bathroom, or y'know whatever common objects you use, but to think about hand hygiene in the same way as in the hospital where y'know you frequently wash your hands, because you're handling things, it doesn't come into play because you're not dealing with patients, and, and any bugs that are in my family are held in common so it, it doesn't become an issue. Ah, i-it's not an obsession like it is in the hospital.

For that reason, participants claimed to practice hand hygiene differently at work than at home. This difference in hand hygiene performance was mainly in terms of compliance and thoroughness.

Setting Context therefore encompasses the output side of the relationships in much the same way that *Culture* does to the input side. In the patient-care environment, the *Decision-Making Process* occurs within the *Setting Context*.

When hand hygiene is to be performed via the *Decision-Making Process*, first the nurse has to decide whether or not she wants to perform hand hygiene. If she decides not to, the process aborts. This process is illustrated in Figure 8.2. If the nurse decides to proceed, then there are three possible avenues that could be followed: *Preference, Convenience* or *Clinical Context*.

Fig. 8.2: DECISION - MAKING PROCESS



Preference

The nurse can decide to perform hand hygiene based on preference for either hand washing or use of alcohol hand-rub. And each preference is determined by self-stated factors such as "*Microsan* is fast, convenient and easy to use", "I don't like the taste *Microsan* leaves on my

hands" and "I have this mentality of soap and water." *Preference*, therefore, has a bearing on the method of hand hygiene the nurse will employ, if she proceeds to perform the hand hygiene. Some of the upstream elements that shaped the meaning of hand hygiene also inform preference of the method to use. For example, the nurse has specific *Beliefs* about alcohol hand-rub and hand washing; and these are informed by her *Education*, *Experience* and *Perceptions* regarding both methods among other upstream categories.

Convenience

When asked about preference, Nurse 18 answered:

N18 A39-41 Umm, I guess it would be um, (pause) whatever's closer. Um, the washing of the hands, I mean now that I've been told that that's more effective (slaps table) I-I will always. The Microsan yea. Um, that I would always, I would always pick that. But I always pick it because it's faster.

The respondent further claimed that despite the fact that she will use whichever is closer, she prefers *Microsan* because it is faster to use. *Convenience* was thus identified as an important category which determines whether or not hand hygiene will be performed.

Clinical Context

This context is different from the *Setting Context*. When present, it exists within the *Setting Context*. Thus, hand hygiene decisions can be made based on the patient's clinical condition, which itself exists within the hospital setting. If the nurse chooses to perform hand hygiene based on the *Clinical Context*, then the overall determining factors will include such considerations as "Is the patient isolated?" "What type of isolation?" "What is the diagnosis behind this isolation?"

Nurse 7 A43 Ahh, we are a unit of course antibiotic resistant bugs are huge, so it's become a, a pivotal p-point, I mean there are so many patients everyday that are isolated, I'm aware that they're isolated, I'm aware of the danger of transmert- of transferring these bugs around. So i-it's it an integral part of the practice it's critical.

The isolation-related clinical factors that featured prominently in the interviews were *C difficile* infection and presence of antibiotic-resistant organisms, especially Methicillin-Resistant *Staphylococcus aureus* (MRSA) and Vancomycin-Resistant *Enterococcus* (VRE.) These were major motivators for hand hygiene compliance. One respondent went further and identified *fear* as the actual motivator for her claimed high compliance. Further probing revealed that it was fear of transmitting infections both ways, as well as further afield to family. But this fear has its roots in the patient's perceived infectious condition, as the nurse had previously mentioned that she is not concerned about infection spread in the home setting.

Participants generally knew when they are required to wash hands as opposed to using alcohol hand-rub (35, 52, 53). Patients with *C difficile* infection and when hands are grossly contaminated were prominently mentioned as situations that call for hand washing as opposed to use of alcohol hand-rub.

The last stage in the *Decision-Making Process* is to settle for either hand washing or alcohol hand-rub use. The previous three options, that is, *Preference*, *Convenience* and *Clinical Context* determine whether the nurse will settle for hand washing or alcohol hand-rub. As with all the other steps, the hand hygiene could also abort at this stage due to a variety of reasons such as "Can't find a sink", "Empty alcohol hand-rub or soap dispensers" etc.

Decision-Making Process and its constituent categories of *Preference*, *Convenience* and *Clinical Context* were evident in some of the answers. When participants were asked how they decide what method to use, some of the answers given were

Nurse 1 A43 Yeah, generally rule of thumb, if you're going in and out of a room, um (pause) you're using the Microsan. Un, like, unless your hands are visibly soiled, um then you're washing them, but all the time mostly is Microsan for me.

Nurse 7 A37 As I said it's about what my hands look like. Um if I feel I've been in contact with feces or something of y'know something that can, that has a lot, high-bacteria load then I use soap and water, but if it's been in contact with surfaces (rubs hand(s) on desk) that lo- appear clean, but may carry bacteria then I use the, the Sandy Foam, the, the Microsan.

Intention

This category constituted the last stage before actual performance of hand hygiene by the *Conscious Decision-Making* route. Asked how they decide which hand hygiene method to use, the nurses gave answers whose execution is only possible through conscious intent. "I always pick *Microsan* because it is faster." "Whichever is closer," or "It depends on how my hands look." This intention is also discernible from statements about what prevents the nurse from performing hand hygiene by their preferred method. Wrong water temperature, fidgety electronic faucets, malfunctioning towel dispensers and watery alcohol hand-rub are some that were mentioned.

Hand Hygiene Act

This is the final stage. It entails either hand washing or use of alcohol hand-rub; or both. Each hand hygiene act is unique, but is performed within the framework of that nurse's overall understanding of what hand hygiene means to her. The individual hand hygiene act is therefore only one event in the nurse's hand hygiene practice. This hand hygiene practice is, in turn, a subset of the nurse's entire nursing practice. From the descriptions of hand hygiene in the interviews, it is evident that *Hand Hygiene Practice* is considered a key component of nursing practice as a whole.

Nurse 1 Ans 1 Well (pause) it's um a baseline for nursing and it means prevent, prevention, protection um (pause) reduction of infectious diseases. It's you know (pause) um it's just basic (pause) nursing um what's the word that I'm looking for? (pause) It's just so important (scratching noise). The basis of all our care is, that's where you start, to, to reduce infections, to prevent infections, to anything like that. So, it's very important

Nurse 7 Ans 1 It means um, protecting the patients and myself from transmission of bugs ah, through proper hand ah care, between any patient contact and when handling materials which may have been used in common with other patients. So for me it's um, a continuing part of my job. I perform hand hygiene many dozens of times every day. And I use the soap and water and I use the um, the um, Microsan as often as I can and probably more frequently, if I feel that I haven't washed my hands lately I'll go and Microsan them.

Nurse 7 A41 I feel that I've really incorporated it into my practice so that now it's y'know. If I don't do it and I, I've done something, touched a patient or touched the equipment I'd be, I'm pretty aware of it so, um, I would say it's almost 100%.

Nurse 7 A43 Ahh, we are a unit of course antibiotic resistant bugs are huge, so it's become a, a pivotal p-point, I mean there are so many patients everyday that are isolated, I'm aware that they're isolated, I'm aware of the danger of transmert- of transferring these bugs around. So i-it's it an integral part of the practice it's critical.

8.3 Thoughts about RFID technology and being monitored

Participants gave mixed responses regarding how they felt about being observed as they went about their work. One nurse felt intimidated while another one was not bothered because it was voluntary. One nurse did not mind because she loves research while another one described the experience as "awkward." However, regarding the requirement of having to wear a tag, all were unanimous that they did not mind. While one felt it was fun, one participant had only what she described as minor reservations regarding privacy, such as during bathroom visits. The nurses also expressed willingness to accept use of the technology in Calgary hospitals if it will contribute to improving hand hygiene performance.

CHAPTER NINE

DISCUSSION

9.1 Introduction

In this chapter, findings from all the three sub-studies are discussed and interpreted. Relationships between the findings are explored. Implications of what the results and findings might mean are also discussed. Possible future studies proceeding from these findings are suggested.

9.2 Sub-Study 1

Radio Frequency ID/Exciter System

Sensitivity for the RFID/Exciter system was 0.175 [0.057, 0.293]. In practical terms, this means that as applied in this study, the system is poor at identifying true hand washing events. The Positive Predictive Value or probability that a detected event is an actual event was 0.778 [0.649, 0.907]. This probability is reasonably high, and the 95% CI is also not unreasonably wide. Sensitivity and PPV are key elements of validity. The low sensitivity means that the system was poor at detecting hand-washing events. However, the reasonably high PPV shows that the probability that detections are real hand-washing events as per study definition is reasonably high, almost 80%. Therefore the system is poor at detecting hand-washing events, but when it detected, they were mostly true events, as per definition.

Validity was defined as the extent to which an instrument measures or detects what it purports to measure or detect. In this application, whenever the RFID/Exciter system made detection, the probability that that detection was correct was almost 80%. However, at a sensitivity of

17%, most of the positives were missed. Thus the system has poor validity when used for detection of hand-washing events.

But the system's test-retest reliability score was 0.266 [0.109, 0.520]. Comparing this result with Nunnally's (91) recommendation that 70% and higher to be considered as reliable, the RFID/Exciter system was well below this mark. Thus when used for hand-washing detection applications, the system was unreliable.

However, it should also be mentioned that at 40, the total number of detectable events was small. These findings therefore should be interpreted with caution.

From the literature review, the studies by Sahud et al. (21) and Cheng et al. (22) were identified as having the closest and more direct relation to sub-study 1. Sahud et al. compared hand hygiene compliance as measured by direct observation with that measured by electronic monitoring. Their findings showed a compliance rate of 32% for direct observation and 25% for electronic monitoring. Their conclusion was that because electronic monitoring recorded many more events, findings from this method may be more reliable than those from direct observation.

Similarly, Cheng et al. (22) aimed at evaluating the performance of the *MedSense* electronic monitoring system. They concluded that the system was unobtrusive and less susceptible to Hawthorne Effect, yet had a performance that was comparable to direct observation.

There is no indication that either Sahud et al. (21) or Cheng et al. (22) tested the validity or reliability of the electronic systems they used. In the current study, this testing was done, showing poor validity and reliability of RFID/Exciter systems for hand-washing detection

applications. If the systems in these two other studies had similarly poor performance, questions may be raised about their findings.

More importantly, findings from the current study also raise questions about whether electronic monitoring can really be a substitute for direct observation, which is considered the gold standard (30, 57, 59-61). Like all other electronic monitoring systems, the current study used a proxy to represent a hand-washing event. Two false events were detected, further showing the difficulty of detecting hand-washing events using proxies. Moreover, when hands were actually washed, it was impossible for the system to assess the effectiveness of the hand wash.

The current study used six exciters in one wing of the 30-bed unit. The poor performance of the RFID/Exciter system as well as its high cost and the fact that electronic systems are unable to detect critical hand hygiene opportunities raise many questions about their practical utility for hand hygiene monitoring purposes in their current form.

Of interest also was the fact that the 40 observed hand washing events constituted 85% of all hand washing events observed. This suggests that correct sinks for the study were installed with the six available exciters. Moreover, the ratio of Corridor Sink Utilization: Room Sink Utilization was 78.7% : 21.3%. This means that wired sinks were used for 85% of the hand washing events and almost 80% of these events were at corridor sinks.

Boyce et al. (47) found that healthcare workers prefer to use sink and alcohol hand-rub dispensers located in the corridors over those located in patient rooms. Findings from the current study agree with this observation.

9.3 Sub-Study 2

9.3.1 Hand Hygiene Compliance

Research Question 2(a) sought to establish whether nurses' hand hygiene compliance is higher for the higher perceived risk factors and lower for the lower ones. With a compliance rate of 0.745 [0.654, 0.819] for aggregated perceived high risk factor and 0.282 [0.233, 0.337] for aggregated perceived low risk factor, nurses evidently have higher hand hygiene compliance for the higher perceived risk factors as compared to lower ones. And these findings are significant with a p-value of <0.0001. Null Hypothesis 1 (H_{o1}) is therefore rejected.

These findings for the aggregated Perceived Low and Perceived High Risk Factors are also true for the individual perceived risk factors, with the exception of three surprises. Perceived Low Risk Factor 2 (After Patient Contact but without Exposure to Body Fluids) had been hypothesized as being a low risk factor. But at 0.692 [0.583, 0.784], it is apparently a high risk encounter as per the hypothesis. Scheithauer et al. (52) and Jenner et al. (64) among others (68, 70, 71) showed that hand hygiene compliance is significantly lower before patient contact than after patient contact. However, all these researchers did not break down exposure to the different types. In this study, we isolated casual exposure from what we considered the riskier exposure, that is, to body fluids. From our findings, any exposure to the patient would be considered a high risk encounter, irrespective of whether or not there was exposure to body fluids. This conclusion agrees with findings from these previous researchers. However, it must be mentioned that these risk perceptions were not discussed with nurses for validation.

From the interviews, it emerged that nurses consider patients as posing the greater infectious risk to the nurse and others than the other way round. These findings, as well as results from the observations validate conclusions by Lankford et al. (77) and Erasmus et al. (105) that nurses' hand hygiene practices are driven by the need for self-preservation. Thus, nurses do not seem to consider themselves to be a potential health hazard to the patient.

With a low compliance rate of 0.286 [0.076, 0.648], Perceived High Risk Factor 3 (After handling heavy contamination) was also a surprise. There were only seven hand hygiene opportunities under this perceived risk factor. In all cases, gloves were worn. This low compliance rate, even when gloves are used, contrasts with the 0.825 [0.726, 0.894] for the isolated patients and 0.778 [0.443, 0.947] for the non-isolated patients. This is surprising as it seems to suggest greater confidence in gloves when handling gross contamination than when caring for the patient. Alternatively, it may also suggest that nurses interpret the message of hand hygiene before and after glove use to be restricted to direct patient-care applications only. This is an area that needs further investigation.

The hand hygiene compliance rates for **Perceived High** Risk Factor 1 (Before Aseptic Procedure) are also surprising. From the hypothesis, it was expected that compliance for **Perceived Low** Risk Factor 1 (Before patient contact) would be low, and these results are in agreement with this. However, at zero compliance, Perceived High Risk Factor 1 (Before aseptic procedure), which carries a high risk of causing blood-borne or wound infections, is not only surprisingly low, but is also the lowest of all observations – and the lowest possible. While this is surprising

for the potential seriousness of the breach, it is in agreement with the findings of Scheithauer et al. (52) that compliance rates before aseptic procedure can be as low as 23%. Although Lankford et al. (77) suggest that hand hygiene practices are dictated by the need for self-preservation by healthcare workers, these results suggest that in terms of consideration for actions that would prevent spread of infections, patient interests have a much lower rating than may have been thought.

However, it is also worth mentioning that only two hand hygiene opportunities were observed for this Perceived Risk Factor (Before Aseptic Procedure) with glove use, although gloves are a requirement where body fluid exposure or aseptic procedure are involved. In light of only these two observations, it may be questionable to make a general conclusion about hand hygiene compliance before aseptic procedure.

It is also worth noting that over the course of the study, there was only one additional hand hygiene opportunity for Perceived High Risk Factor 1 (Before Aseptic procedure). During this opportunity, gloves were not worn and hang hygiene was not performed.

Just as Perceived High Risk Factor 1 (Before Aseptic Procedure) is a high risk event, Perceived High Risk Factor 2 (After exposure to body fluids), which would follow every Perceived High Risk Factor 1 event must also be a high risk event. Looking at Perceived High Risk Factor 2 (After exposure to body fluids) events that immediately follow these three Perceived High Risk Factor 1 events, there was hand hygiene compliance in both cases when gloves were used. However, in the single event when no gloves were used, neither was hand hygiene performed after the exposure to body fluids. Tracing it back to the individual, this was nurse No. 11, whose overall compliance was 0.200 [0.063, 0.460]. This was the lowest individual rate among all twenty

participants. This participant is evidently an outlier. It would therefore be unreasonable to generalize findings from this single nurse's hand hygiene practice to the rest of the unit. However, although coming from one nurse only, these findings are in agreement with findings by Scheithauer et al. (52) that hand hygiene compliance tends to be poor for situations with most severe outcomes for patients.

In a medical ward such as the one in this study, aseptic procedures would include activities like insertion of a urinary catheter and other invasive procedures. In comparison to the other Perceived Risk Factors, these activities are relatively infrequent on a medical unit. This might explain the low number of observations. Also, the invasive nature of these procedures suggests that nurses would more often be performing them behind closed doors or drawn curtains. Also, these are likely to be performed towards the end of shift. Our observation period was typically the first two hours of a shift. Therefore only very few of these events could have been witnessed by the observer.

Hand hygiene compliance has been shown to be significantly lower before patient contact than after patient contact (52, 64, 68, 71). Compliance rates for before and after patient contact from the current study agree with this observation. Lankford et al. (79) had theorized that healthcare workers' hand hygiene may be driven by perceived risk to themselves, and not risk to the patient. And in their study, Erasmus et al. (105) had also come to the conclusion that beliefs about the importance of self-protection are the main reason for performing hand hygiene. Fulkerson's scale was a rudimentary attempt at measuring compliance and technique based on perceived risk, but as Taylor et al. (41) found, the scale was irreproducible, and thus, validity of findings questionable.

The current study took the work by Lankford et al. (77) a step further and tested it out with numerical values. To the best of our knowledge, this is the first study to evaluate hand hygiene compliance based on hypotheses on how nurses would categorize risk of infectious exposure. These risk factors were defined based on the exhaustive *My Five Moments* (Figure 2.1) template. Thus, in comparison with the basic before-and-after patient contact considerations that had been performed by Scheithauer et al. (52) and the other researchers (21,68,70,71), the entire spectrum of infectious risk possibilities around patient care was incorporated in this study. And a p value of less than 0.0001 suggests that these findings are very significant, to 95% confidence interval.

9.3.2 Effect of Gloves

Gloves were routinely used for isolation cases, as is required. The strong correlation of 73.9% between glove use and isolation confirms this. Looking at Table 6.5, the hand hygiene compliance for before contact with patient or patient environment (Perceived Low Risk Factor 1) and before glove use are 10% and 8% respectively. The rates for after contact with isolated patient or his environment (Perceived High Risk Factor 4) and after glove use are 82% and 80% respectively. And those for after contact with non-isolated patient (Perceived Low Risk Factor 2) are a sizeable 69%.

Although during the interviews the nurses all said hand hygiene should be performed before and after patient contact, they also said hand hygiene must be performed after glove use. And these results show that compliance was much higher after patient contact or glove use as compared to before patient contact or glove use. Also, 91.4% of all observed glove usage was in

relation to patient care. The remaining 8.6% was non-patient care, that is, Perceived High Risk Factor 3 (handling heavy contamination e.g. shoes, garbage bin etc).

This observation reinforces the perception that nurses are more conscious about self-protection from the patient than they are about patient protection from infectious risk.

As was observed, 91.4% of the times gloves were worn, it was for direct patient-care. That nurses could say hand hygiene before and after patient-care and hand hygiene after glove use, yet not before glove use, shows a deficiency in knowledge or a pervasive oversight. This means that when gloves were used, hand hygiene Moment No.1 (Before contact with patient) was routinely missed, thus the poor compliance of 8%.

More than 90% of all glove use was for patient-care. Hand hygiene compliance after glove use was 80%; after exposure to isolated patient was 81% and after exposure to non-isolated patient was 69%. These findings suggest that hand hygiene compliance is higher after gloves are used compared to when gloves are not used.

If healthcare workers' primary reason for performing hand hygiene is self-protection as was suggested by Lankford et al. (77) and Boyce et al. (30) among others, then hand hygiene after exposure to isolated patients or their environment, which would be perceived as constituting one of the greatest risk to the nurse should be quite high. And as Lankford et al. (77) suggested, glove use would also be high, and could, in fact, be used as a marker for hand hygiene compliance. Comparing these two figures, compliance after glove use, 0.802 [0.708, 0.872], is almost identical with compliance after exposure to isolated patient or his environment, 0.816 [0.713, 0.888].

Thus, compliance after glove use essentially mirrors compliance after exposure to isolated patients. Therefore, gloves, which are primarily used in patient-care, are largely used for isolated patients. And compliance after glove use is essentially the same as compliance after exposure to isolated patients. This finding supports conclusion by Lankford et al. (77) that glove use could be used as a marker for hand hygiene compliance. However, our finding that hand hygiene when gloves are used mirrors that for after exposure to isolated patient is new, but agrees with the concept that self-preservation is the driving force behind hand hygiene compliance.

9.3.3 Shift-Based Hand Hygiene Compliance

Shift-based compliance shows a clear graduation with compliance for Day>Night>Evening. This is in contrast with Scheithauer et al. (52) who found no significant difference across shift lines. Reasons for the variations in our findings are not clear. In light of the discrepancy between these two findings and the absence of any other in the literature, hand hygiene variation across shift lines is an area that warrants further research.

9.3.4 Hand Hygiene Duration

The objective of Research Question 2(b) was to investigate whether the duration of hand hygiene events also increases with Perceived Risk Factors. Results for hand hygiene duration can be divided into two parts: (i) alcohol hand-rub use and (ii) hand washing component.

Alcohol Hand-Rub Use

Hand hygiene duration for alcohol hand-rub was found to be generally stable at 4.5 to 4.8 seconds irrespective of the perceived risk factor. This stable duration is likely due to the simple instructions for using alcohol hand-rub: “One or two pumps followed by rubbing hands on all

surfaces until dry." Results suggest that this process is adequately achieved in about 4.5 seconds for most people.

This duration is also, therefore inherently independent of any perceived risk factor, as the requirement is "until dry." This may explain the relative stability of the alcohol hand-rub graph as compared to that of hand washing. Therefore from our findings, we conclude that within the hospital unit, the duration of hand hygiene using alcohol hand-rub is approximately 4.5 seconds, and is independent of perceived risk factors.

Hand Washing

Hand washing duration for aggregated Perceived Low Risk Factor was 4.3 [3.4, 5.3] seconds while that for aggregated Perceived High Risk Factor was 6.4 [4.9, 7.9] seconds. There is therefore a clear two second difference between the durations of the two Perceived Risk Factors. This represents a 48.8% difference between the two values. The significance of these findings is confirmed by a p-value of <0.0001.

Null Hypothesis 2 (H_{o2}) stated that: Nurses' hand hygiene duration is not longer for perceived high infectious risk associated with the nurse-patient interaction than for perceived low infectious risk. Like Null Hypothesis 1, this hypothesis is therefore also rejected. To 95% Confidence Interval, nurses' hand hygiene duration is longer for perceived high infectious risk associated with the nurse-patient interaction than for perceived low infectious risk.

In introducing modifications to Feldman's Criteria, Larson (16) and Gould (33) introduced the element of duration of the hand wash as a key element of hand washing technique. In this study, both hand hygiene compliance and quality of the hand-wash were tested with regard to the perceived exposure. Duration was taken as a marker for technique, and thus quality of the

hand-wash. The p-value suggests that these findings are indeed significant. However, as with Fox et al. (34), we also found that duration of the hand-washing act fell below the recommended minimum period. This problem was so severe that in Part I of the study, dwell time had to be lowered from five seconds to one second. The minimum recommended hand washing duration being 15 seconds (30, 53, 70), the practical utility of a four, five or even seven-second hand-wash is questionable.

The findings in this study suggest that compliance is higher and duration of hand wash is longer for perceived high infectious risk, and especially if the risk is to the nurse. This agrees with the conclusion by Lankford et al. (77) and confirms it in a measurable way.

As with hand hygiene compliance, to the best of our knowledge, this is the first study to evaluate duration of a hand wash with respect to the perceived risk associated with the exposure.

It should be mentioned that because the total hand washing events were so few, many nurses clocked only two or three events. Calculations for individual nurses therefore yielded unreliable, wide-confidence interval values, some crossing into meaningless negative time. Similar problems were encountered for nurses who had very few alcohol hand-rub events. In light of this problem, analysis for individual nurses was not performed. Priority was given to aggregated data as results from this would be more statistically meaningful.

9.4 Sub-Study 3

From the interviews and inductive analysis using the Grounded Theory approach, *Meaning* emerged as the central category in hand hygiene practice. Upstream categories formulated the meaning of hand hygiene, and hand hygiene action proceeded from this *Meaning*. Foster et al.

(92) had strongly argued about the importance of focusing on behavior change than access to hand hygiene products as a strategy for improving hand hygiene practice. Both the Theory of Planned Behavior and Health Belief Model showed that hand hygiene behavior is predictable to an extent and therefore modifiable.

The theory from sub-study 3 showed that using the conscious decision-making route, hand hygiene is predictable, and therefore modifiable. By that route, the theory is in agreement with TPB and HBM. But the primary modifying factors are the upstream influences which give rise to *Meaning* of hand hygiene. All these factors, such as *Attitude*, *Knowledge* and *Beliefs* are social and behavioral/psychological influences. The *Habit* route is also informed by *Meaning* but cannot be predicted.

Thus, findings from this study agree with Foster et al. (92) that social and behavioral factors that influence hand hygiene should be accorded more attention than they are currently receiving. This argument is strengthened by the findings that the current emphasis on basic counts and compliance measurements is leaving out the key hand hygiene element of technique, and therefore Quality.

The central conclusion from sub-study 2 was that duration and compliance of nurses' hand washing practices were informed by their perceptions about the risk associated with their interaction with the patient. But *Perceptions* were identified in sub-study 3 as one of the upstream categories which inform *Meaning*, and therefore hand hygiene practice.

The conclusion therefore is that focusing on positively changing the categories of *Perceptions, Attitudes, Beliefs, Education, Knowledge* and *Experience*; and creating a conducive *Cultural*

environment stand a better chance of positively influencing the *Meaning* of hand hygiene and therefore *Hand Hygiene Practice*.

9.5 Thoughts about being studied and the technology

Participants gave mixed responses regarding how they felt about being observed as they went about their work. One nurse felt intimidated while another one was not bothered because it was voluntary. One nurse did not mind because she loves research while another one described the experience as “awkward.” However, regarding the requirement of having to wear a tag, all were unanimous that they did not mind. These findings are in agreement with the findings of Boscart et al. (27). While one felt it was fun, one participant had only what she described as minor reservations regarding privacy, such as during bathroom visits. The nurses also expressed willingness to accept use of the technology in Calgary hospitals if it will contribute to improving hand hygiene performance.

9.6 Study Strengths

This study had a number of strengths

From the literature review, it was evident that there was a paucity of literature on hand hygiene technique and quality. Several possible reasons were mentioned. These largely revolved around the complex nature of hand hygiene, including the process and multiple hand hygiene options as well as the many variables that influence hand hygiene practice. We believe that employment of mixed methods approach was the best design for this study with multiple objectives.

Better understanding of the findings from sub-study 2 was possible from results of sub-study 3. And the hand hygiene relationships in sub-study 3 were developed and constantly back-

checked against interview data using the Grounded Theory approach. This continuous validation ensured that the emerging theory was as close to the data as possible. And the interviewees had been selected based on the results they had shown in sub-study 2. This synergistic relationship in design ensured that the final findings would be a as close to the true picture as possible.

Although there were difficulties in selecting representative samples for both all the sub-studies, random elements such as not knowing who will be assigned to the 'C' wing on which day and a structured interviewee selection process for sub-study 3 were incorporated in the design to meet these challenges and minimize selection bias.

For sub-studies 1 and 2, where direct observation was done, measures were put in place to minimize Hawthorne Effect. These included blinding the nurses to the actual data being collected and avoiding possible association between a hand hygiene station visit and observer writing.

In sub-study 3, greater emphasis was given to the Theory of Planned Behavior because of its stronger behavior-predictive power over the Health Belief Model (88). However, because each model has its weaknesses, elements of both models were used for a more complete understanding of hand hygiene behavior.

9.7 Study Weaknesses

The study, too, had a number of weaknesses. The primary assumption for sub-study 1 was that a healthcare worker wearing an electronic tag and dwelling at a wired sink for the duration of the dwell time was likely to be performing hand washing. The assumption had its own inherent deficiencies. Despite the small number of 40 sink visits being made at wired sinks and seven

detections, one detected event already exposed the assumption's weakness. A nurse could, indeed dwell at the sink for the pre -set dwell time and still not be washing her hands. However one such false detection against 40 observations could also be considered reasonable for a study. In addition, the Dwell Time had been lowered to a clinically meaningless one second. But if nurses were to be washing hands for the required duration of at least 15 seconds, the Dwell Time would have remained at five seconds. Under those settings, this towel pick event would not have registered as a detected event. Thus **Assumption 1** would have had an even stronger justification. This assumption was therefore not considered unreasonable.

There was one unknown event detected by the Radio Frequency ID/Exciter system. However, observer recording shows that the event occurred at a real time when the nurse was in a patient room with the door closed. The door was often closed when nurses were administering personal care to patients. And this particular room had a wired sink. It is therefore most likely that this was a valid detected event. But it could also have been another paper towel incident, where a nurse goes for a paper towel for no apparent reason; or any other false detection. The observer did not witness the event. It was therefore recorded as an unknown. Classification of this event also created a dilemma. Was it a false positive or a true positive? Should it be omitted altogether? Only true detections that were witnessed were considered true detected events. This event was therefore classified as a false positive. The study design did not envisage the possibility of un-witnessed, yet detected events, and how to classify them.

The adoption of hand hygiene duration as a marker for quality also raises some questions. *Duration* is not the only (or necessarily the most important) component that defines an effective hand hygiene act. Indeed, it is possible to wash hands for a full minute or more

without good effect. Other central elements of hand hygiene quality such as type of soap, soap utilization and overall hand hygiene technique were not monitored in this study.

Therefore from a practical clinical effectiveness perspective, the use of duration alone as a representation of hand hygiene quality was a study weakness. However, from a study design perspective, Research Question 2(b) was based on duration itself, and not quality as a whole. Additionally, considering the complexity of the lead-up to a hand hygiene event, with multiple variables within *quality*, it was deemed reasonable and more manageable to focus on one key element within the hand hygiene *quality* cluster.

Patient isolation was lumped together as one element. No distinction was made between protective isolation, isolation due to communicable conditions or due to the presence of a resistant organism. Also, no distinction was made between perceived risk of transmission patient-to-nurse and nurse-to-patient. Thus the variation of hand hygiene compliance for different isolation types remains unknown.

Accuracy of hand hygiene duration was also an area of weakness. There was need to maintain blindness as to what exactly was being monitored. Thus, seconds were quietly counted, giving an approximate figure like 4 seconds where a stop-watch would have given, say 3.6 seconds. But the approximation had been tested and found to be reasonably accurate. Thus the conclusion would likely to have been the same even with the use of more accurate timing.

9.8 Future Studies

The current study was observational and exploratory. As the potential of hand hygiene to significantly impact patient outcomes and healthcare costs was clearly identified in the

literature, follow-up studies, especially leaning on interventions, should be considered. From the findings of these studies, the following questions arise:

Hand hygiene compliance of nurses (and potentially other healthcare workers), as well as the duration of their hand washing increase with what they perceive as risk factors associated with the nurse-patient interaction. If these perceived risks factors are graded and weighted for potential severity on outcomes as Larson (16) did with Fulkerson's Scale on Feldman's Criteria; and healthcare workers educated based on this new template, will there be better patient and cost outcomes?

The matter of sub-conscious performance of hand hygiene in a patient-care environment seemed rather odd. Is this possible? If it is, what else is done sub-consciously in this environment that calls for deliberate, intentional action in everything that is done?

This study considered patient isolation as one unit. Does hand hygiene practice vary with the different isolation types?

The *Meaning* of hand hygiene to the individual emerged as critical link between the *Input Side* and the *Output Side* of the *Hand Hygiene Relationships*. A more detailed exploration of how *Meaning* of hand hygiene affects hand hygiene practice might be helpful in shedding more light on the impact of this important element of hand hygiene practice.

Participants gave mixed views regarding how they felt being observed as they did their work. But they were agreeable to wearing an electronic tag, in addition to endorsing the technology if it will improve hand hygiene practice. Sahud et al. (21) and Cheng et al. (22) concluded that electronic monitoring was unobtrusive but yielded comparable results with direct observation. In light of these observations, as well as the discomfort with direct observation, future studies

may investigate the possibility of replacing direct observation with electronic monitoring as gold standard for hand hygiene monitoring.

The objective of hand hygiene practice is to rid hands of organisms and other contaminants. From Sub-study 1, measurement techniques primarily focus on hand hygiene compliance with almost no mention of technique and quality of the act, and therefore effectiveness of the hand cleaning act. But the literature points to the need for greater attention on hand hygiene practice from a behavioral perspective (17,87). Should more focus be on behavior change than on HH compliance measurement, the quality of which cannot be ascertained?

Sub-study 2 was based on nurses' hypothesized perceptions about infectious risks associated with patient interactions. However, it is still unclear if these perceptions are real. A future interview study focusing on this would help to confirm or nullify this hypothesis.

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APPENDIX A

APPENDIX A (cont'd)

APPENDIX A (cont'd)

APPENDIX B

CONSENT FORM (for Sub-Studies 1 and 2)

TITLE: Ward of the 21st Century Radio-Frequency-Identification Location Tracking Evaluation

SPONSOR: IBM/AeroScout

INVESTIGATORS: Dr. William Ghali, Dr. Marina Gavrilova, Dr. Barry Baylis, Dean Yergens, William Ward Flemmons, Bill Trafford, Alecia Greenough, Joseph Kaunda

BACKGROUND

RFID is a mature technology used for locating, tracking and identifying items. It is similar to barcoding, except more advanced in that there need not be a direct line-of-sight between a scanner and the barcode. Producers of such technology have made claims that it can greatly improve asset management, caregiver workflow and patient and staff safety.

This study intends to examine the usefulness of such technology in an applied medical care setting (Unit 36.)Approximately 10 nurse and 20 physician volunteers will participate in this study.

WHAT IS THE PURPOSE OF THE STUDY?

The purpose of this study is to determine the usefulness of RFID Wi-Fi technology in an applied healthcare setting. It is a pilot project on Unit 36 and could potentially have impact on Calgary Health Region decision regarding future purchase of such technology. Also by gathering time and location data of healthcare providers, insight is gained that can lead to superior hospital layout design. Specifically, this information may be used for the design of the South Health Campus.

WHAT WOULD I HAVE TO DO?

If you volunteer to participate in this study, you will be required to wear an RFID tag for one 8-hour shift. The tag can be worn around your neck on a lanyard or clipped to your shirt. The RFID tag is about the size of a regular identity badge. You will be given the tag by a research assistant at the start of your shift, and must return the tag at the end of your shift. During this time, a range of items will be assessed by means of the locator, with all the items having been approved by CHREB.

For some phases of this study, a research assistant may "shadow" you for part or all of your shift. The research assistant will be manually entering time and location data so that it may be compared to the time and location data as measured by the RFID tag Wi-Fi System. A full debriefing will be provided to participants orally and in written form upon the completion of the study.

WHAT ARE THE RISKS?

There are no risks involved in this study. The RFID tag you will wear complies with Health Canada's Code 6, which regulates radio-emitting equipment in medical settings. The amount of radiation emitted from an RFID tag is only a small fraction of the amount emitted by a cell phone.

ARE THERE ANY REPRODUCTIVE RISKS?

None

WILL I BENEFIT IF I TAKE PART?

By participating, you will contribute to valuable knowledge acquisition and in an emerging area.

DO I HAVE TO PARTICIPATE?

No. Participation is voluntary.

WHAT ELSE DOES MY PARTICIPATION INVOLVE?

Nothing

WILL I BE PAID FOR PARTICIPATING, OR DO I HAVE TO PAY FOR ANYTHING?

No.

WILL MY RECORDS BE KEPT PRIVATE?

Yes. During the 8-hour shift, an abundance of moment-by-moment time and location data will be generated automatically as you wear the tag. Your personal identity will not be connected to these data; rather, your role as a healthcare provider will be attached to the data.

For example, data shall be identified as "nurse 1," "nurse 7," "sr.resident4," "attending.physician3," etc.

IF I SUFFER A RESEARCH-RELATED INJURY, WILL I BE COMPENSATED?

There is no risk associated with this research study.

SIGNATURES

Your signature on this form indicates that you have understood to your satisfaction the information regarding your participation in the research project and agree to be a participant . In no way does this waive your legal rights nor release the investigators, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time without jeopardizing your health care. If you have further questions concerning matters related to this research, please contact:
Dr. William Ghali (403) 210-9317
If you have any questions concerning your rights as a possible participant in this research, please contact Pat Evans, Associate Director, internal Awards, research Services, University of Calgary, at (403) 220-3782.
Date and time of availability: ----------

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Participant's Name	Signature and Date
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Investigator/Delegate's Name	Signature and Date

The University of Calgary Conjoint Health Research Ethics Board has approved this research study.
A signed copy of this consent form has been given to you to keep for your records and reference.

APPENDIX C

CONSENT FORM (for Sub-Study 3)

TITLE: Ward of the 21st Century Radio-Frequency-Identification Location Tracking Evaluation

SPONSOR: IBM/AeroScout

INVESTIGATORS: Dr. William Ghali, Dr. Marina Gavrilova, Dr. Barry Baylis, Dean Yergens, William Ward Flemmons, Bill Trafford, Alecia Greenough, Joseph Kaunda

BACKGROUND

RFID is a mature technology used for locating, tracking and identifying items. It is similar to barcoding, except more advanced in that there need not be a direct line-of-sight between a scanner and the barcode. Producers of such technology have made claims that it can greatly improve asset management, caregiver workflow and patient and staff safety.

This study intends to examine the usefulness of such technology in an applied medical care setting (Unit 36.)Approximately 10 nurse and 20 physician volunteers will participate in this study.

WHAT IS THE PURPOSE OF THE STUDY?

The purpose of this study is to determine the usefulness of RFID Wi-Fi technology in an applied healthcare setting. It is a pilot project on Unit 36 and could potentially have impact on Calgary Health Region decision regarding future purchase of such technology. Also by gathering time and location data of healthcare providers, insight is gained that can lead to superior hospital layout design. Specifically, this information may be used for the design of the South Health Campus.

Data from this second part of the study will help us to understand the user's perspective of the technology.

WHAT WOULD I HAVE TO DO?

If you volunteer to participate in this second part of the study, you will sit in a secure and confidential room with the interviewer. This will be within the unit or any other available room within the hospital or in the adjacent Medical School. The interviewer will then ask you a number of questions regarding the first part of the study and use of the technology. During the interview, the interviewer will audio-record the discussion. The interview will last between 45 and 60 minutes.

WHAT ARE THE RISKS?

There are no risks involved in this study.

ARE THERE ANY REPRODUCTIVE RISKS?

None

WILL I BENEFIT IF I TAKE PART?

By participating, you will contribute to valuable knowledge acquisition and in an emerging area.

DO I HAVE TO PARTICIPATE?

No. Participation is voluntary.

WHAT ELSE DOES MY PARTICIPATION INVOLVE?

Nothing

WILL I BE PAID FOR PARTICIPATING, OR DO I HAVE TO PAY FOR ANYTHING?

No.

WILL MY RECORDS BE KEPT PRIVATE?

Yes. A lot of data will be collected during the interview. However, your personal identity will not feature anywhere. You will be assigned an anonymous number such as "Nurse-1" or "Nurse-5." The audio recordings will be transcripted and data collected from the transcripts ascribed to the anonymous identifiers mentioned above.

IF I SUFFER A RESEARCH-RELATED INJURY, WILL I BE COMPENSATED?

There is no risk associated with this research study.

SIGNATURES

Your signature on this form indicates that you have understood to your satisfaction the information regarding your participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the investigators, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time without jeopardizing your health care. If you have further questions concerning matters related to this research, please contact:
Dr. William Ghali (403) 210-9317
If you have any questions concerning your rights as a possible participant in this research, please contact Pat Evans, Associate Director, internal Awards, research Services, University of Calgary, at (403) 220-3782.
Date and time of availability: ----------

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Participant's Name	Signature and Date
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Investigator/Delegate's Name	Signature and Date

The University of Calgary Conjoint Health Research Ethics Board has approved this research study.
A signed copy of this consent form has been given to you to keep for your records and reference.

APPENDIX D

INTERVIEW QUESTIONS

1. What does hand hygiene mean to you?
2. Do you practice hand hygiene the same way all the time? [***Probe for when it is done differently***]
3. What is a proper hand wash?
4. What is proper use of alcohol gel?
5. If performing hand hygiene for the recommended duration is 100% and not performing hand hygiene at all is 0%, at what level do you rate your typical hand hygiene event?
6. Is there a difference between washing hands with soap and water and using alcohol gel? [***Probe for perceived differences or similarities***]
7. Do you have any preference between hand washing and using alcohol gel for hand hygiene? [***Probe for reasons of preference or lack of preference***]
8. How do you decide when to wash hands and when to use alcohol gel?
9. If performing hand hygiene whenever you are supposed to is 100% and not performing hand hygiene at all is 0%, how do you rate yourself?
10. In the course of your work, how important is it to perform hand hygiene?
11. What factors play a role in your performance of hand hygiene? [***Probe for what role they play and how***]
12. As a nurse, when are you supposed to perform hand hygiene?
    - Do you always do this?

      YES: [***What is the secret of your success?***]

NO: [***What factors hinder you?***]

13. What do you think about the use of gloves in relation to hand hygiene?

14. How did you feel about being observed as you did your work?

15. During the study, you were required to wear an electronic tag. What are your thoughts regarding use of electronic monitoring in the course of doing your work?

16. Did the awareness that you were being observed affect how you did your work?

    YES: [***How***]

    NO: [***What is the reason for this?***]

17. If this technology is found to be effective in improving hand hygiene compliance, would you recommend its adoption for use in Calgary hospitals?

    YES: [***Please explain a bit more***]

    NO: [***Please explain a bit more***]

18. Do you have any other thoughts, comments or questions for me?

19. Thank you for your time and willingness to participate in this study.

APPENDIX E

CATEGORIES

QUESTION	Participant	Q. Ref.	Ans. Ref.	ANSWER	CATEGORY
What does hand hygiene mean to you?	Nurse 1	Q1	A1	1 - Fundamental for nursing 2 - Preventing and protection of disease 3 - Reduction of infectious diseases 4 - Starting point of all our care 5 - Very important	1-3/5 - Meaning 4 – Meaning/Education/Culture/Nursing Practice
	Nurse 18	Q2	A2	1 - Very important	1 - Meaning
			A3	2 - Related to everything that goes around in hospital	2 - Meaning
	Nurse 12	Q2	A2	1 – Proper hand washing and 2 – Regular use of Microsan	1 - Method 2 - Method
			A4	3 – Washing with soap and water as well as using Microsan	3 - Method
			A6	4- Using both	4 - Method
			A7	5 – Sometimes you use Microsan and other times soap and water	3 – Method/Preference/Knowledge/Education
	Nurse 7	Q1	A1	1 – Protection of patient and self from transmission of bugs 2 – Done between any patient contact 3 – When handling materials used in common with other patients 4 – A continuing part of my job 5 – I perform it many dozen times per day 6 – I use soap and water 7 – I use Microsan as often as I can, probably more frequently 8 – I use Microsan if I feel I haven't washed my hands lately	1 – Meaning/Knowledge/Belief 2 – Knowledge/Education/Nursing Practice 3 – Knowledge/ Education 4 – Nursing Practice 6/7 – Method/Preference 8 – Decision-Making Process
			A2	9 - It becomes an obsession (*use of Microsan?*)	9 - Habit
	Nurse 11	Q6	A11	1 – Very important 2 – To prevent infection, especially in hospital 3 – I think we underestimate its importance	1 – Meaning 2 – Meaning/Belief/Knowledge/Setting Context 3 – Meaning/Knowledge