From DEPARTMENT OF CLINICAL SCIENCE,
INTERVENTION AND TECHNOLOGY (CLINTEC),
DIVISION OF RADIOGRAPHY
Karolinska Institutet, Stockholm, Sweden

HYGIENE AT CT AND MRI

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Stockholm 2020

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Published by Karolinska Institutet.
Printed by **Arkitektkopia AB**

ISBN 978-91-7831-866-7

HYGIENE AT CT AND MRI

Thesis for licentiate degree

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ABSTRACT

Background: Preventing the spread of infections is a constant battle against microorganisms. Hospital-acquired infections (HAIs) with multidrug-resistant (MDR) bacteria are a global problem today and causes suffering for patients and have high costs for society. In a hospital environment, patients with various illnesses and injuries meet, a large proportion of these people will also pass the radiology department, which places high demands on good hygienic standards to avoid HAIs. Although much research has been conducted on hygiene routines and the spread of infection in healthcare, most of the research has not focused on the radiology department.

Aims: The overall goal of this thesis was to study hygiene in public and private radiology departments' CT and MRI facilities with a focus on bacterial growth and the attitude of staff and managers to hygiene guidelines. The purpose of Study I was to identify selected hand-touched surfaces inside and outside the CT and MRI examination rooms that are prone to contamination and might represent a risk for transmission of HAI pathogens. We also aimed to examine if there were differences in bacterial contamination between public and private radiology departments. The purpose of Study II was to investigate the compliance with basic hygiene guidelines among the staff working with CT and MRI and the managers' approaches to basic hygiene routines. Finally, we aimed to examine differences in adherence to hygiene guidelines among staff employees within public and private radiology departments.

Material and Methods: The same radiology departments participated in Study I and II (six public and four private radiology departments). For Study I, bacterial samples were taken from selected hand-touched surfaces inside and outside CT and MRI examination rooms. Sampling was carried out between patients after standard cleaning procedure, using flocked nylon swabs. The swab was applied over a 100 cm^2 surface, and after cultivation the number of, bacterial colony forming units (CFU) per cm^2 was calculated, with values >2.5 CFU/cm^2 being indicative of contamination. Study II was based on a survey data. One questionnaire was distributed to the staff working with CT and MRI with questions about basic hygiene guidelines. The second questionnaire was distributed to managers, also with questions about basic hygiene guidelines. A total of 250 surveys (210 for CT- and MRI staff and 40 for managers) were distributed in paper format at the radiology departments during the autumn of 2016. Closed questions were summarised in frequency tables, and comparisons between groups regarding categorical data were analysed using Fisher´s exact test, and t-test was carried out to compare continuous variables. The open questions were analysed with inspiration from manifest qualitative and quantitative content analysis.

Results: The results of Study I did not show any growth of MDR bacteria, however surfaces were found where the number of CFU exceeded the limit value of 2.5 CFU/cm^2. Keyboards, chairs in the patient changing rooms, headphones, and the alarm control/buzzer were found to be the most contaminated surfaces. The least contaminated surfaces were the medicine trolley and the sides of the MRI tunnel. There was no significant difference between public and private radiology departments. The results of Study II showed that the main reasons why staff working with CT and MRI did not follow basic hygiene guidelines were stress, lack of time, and the occurrence of emergency situations. The managers also believed that stress and lack of time were strong reasons for why staff did not follow the basic hygiene guidelines. Most staff working with CT and MRI in both public and private radiology departments reported adequate hygiene knowledge. Among the variances that emerged between staff working in public and private radiology departments, there, was a significant difference ($p = 0.007$) regarding the compliance with not wearing rings, bracelets or nail polish while performing patient-related work. There was also a significant difference ($p < 0.001$) regarding the use of plastic aprons when there was a risk of contaminating the work clothes. There was also a significant difference ($p = 0.003$) between how the staff of public and private CT and MRI facilities cleaned the examination tables between each patient.

Conclusion: Identified areas within CT and MRI in both public and private radiology departments, that need more disinfection are keyboards, chairs in the patient changing rooms, headphones, and the alarm control/buzzer. No MDR indicator microorganisms were found in the study, and there were no significant differences between public and private radiology departments. The main reasons why the staff both in public and private CT and MRI did not follow the hygiene guidelines were stress, lack of time, and emergency situations. Among the significant differences that emerged between staff working in public and private radiology departments were wearing bracelets, rings and nail polish in patient-related work, and the use of plastic aprons, and disinfection of the examination table between patients.

LIST OF SCIENTIFIC PAPERS

I. **Surface contaminaton of CT and MRI – a potential source for transmission of hospital-acquired infections.**

Charlotte Palmqvist, Anders Samuelsson, Inga Fröding, Christian G. Giske. Journal of Radiology Nursing 2019; 38: 254-260

II. **Adherence to hygiene guidelines among staff working with CT and MRI.**

Charlotte Palmqvist, Anders Samuelsson, Christian G. Giske. Manuscript

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LIST OF ABBREVIATIONS

ACC	Aerobic Colony Counts
CDC	Center for Disease Control and Prevention
CFU	Colony Forming Unit
CPE	Carbapenemase-Producing Enterobacteriaceae
EPE	Extended-Spectrum Beta-Lactamase Producing Enterobacteriaceae
CT	Computed Tomography
ESBL	Extended Spectrum Beta-Lactamase
HAI	Hospital Acquired Infection
MDR	Multidrug-Resistant
MRI	Magnetic Resonance Imaging
MRSA	Methicillin-resistant *Staphylococcus aureus*
VRE	Vancomycin-Resistant Enterococci

1 INTRODUCTION

"*No risk is more fundamental than the risk of infection*"[1] (page 5)

"The lady with the lamp" Florence Nightingale (1820–1910)[2,3] was together with Ignaz Semmelweis (1818–1865) one of the pioneers in the field of infection control.[4] Nightingale grew up in England in a well-kept family and had a strong sense of urge to do something for humanity since childhood.[5] She educated herself as a nurse and worked, among other things, during the Crimean War in a hospital where she improved the survival of the soldiers by working for good sanitary conditions. Thereafter, she founded the first professional schools for nurses and midwifes. Nightingale also wrote books, including "Notes on Nursing and Notes on Hospitals".[2] These books reveal what is required for a healthcare environment to reduce contagious spread and in them she describes her milestones for reducing the spread of infection, including pure air, pure water, efficient drainage, cleanliness, and light.[3]

Semmelweis was a Hungarian physician educated in Vienna,[6] where he later took employment at the Department of Obstetrics at Allgemeine Krankenhaus. There he observed that women died of childbed fever to a greater extent (13–18%) in a department administered by doctors and medical students compared to a department managed by midwives and midwife students (2%). Based on this, he expressed the hypothesis that doctors and medical students transferred infections to these women when they went from autopsies without washing their hands before examining the women. Semmelweis set up a study where the doctors and medical students would wash their hands with chlorine lime water before they went to the obstetrics department, causing the mortality to fall to 2%. Although Semmelweis so clearly in his study was able to demonstrate the importance of washing hands to reduce infection, it would take two decades after his death before this was acknowledged.[7] A long time has elapsed since Nightingale and Semmelweis worked out guidelines for reducing infection spread in healthcare.4 Nevertheless, it remains a highly relevant topic. Hand washing and hygiene in care facilities continue to be extensively discussed, and there is a growing problem with hospital-acquired infections (HAIs) and the dissemination of antibiotic-resistant bacteria in healthcare.[8]

1.1 HOSPITAL-ACQUIRED INFECTIONS

An HAI, also called a nosocomial infection, is an infection that the patient acquires during stay in the hospital.[9] According to the WHO, a disease is classified as an HAI if it breaks out within 48 hours after the patient has arrived at the hospital or other care institutions and was not present or incubating at the time of admission.[10] HAIs also include diseases that break out within three days after leaving the hospital or within one month after an operation.[11] Around 15 % of all hospitalised patients suffer from an HAI, with rates of 7% in developed countries and 10% in developing countries according to the WHO.[12,13] In Sweden, approximately 57,000 patients are affected each year by an HAI.[14] HAIs are the most common complications of medical treatment and make up a third of all care-related injuries, and 4.5% of all patients who are hospitalised contract an HAI. For patients suffering from an HAI, the duration of care is extended by an average of 10 days. The cost of HAIs, which could have been avoided, is estimated at € 0.138-0.203 billion per year.

1.1.1 Types of hospital-acquired infections

A classification of HAIs was published in 1988 by the Center for Disease Control and Prevention (CDC), where HAIs were divided into 13 types, with 50 infection sites.[12,15] In order to identify HAIs, a combination of different examinations were used such as clinical findings in the patients, laboratory analyses, and diagnostic studies with, for example, biopsies and X-ray examinations.[15] The most common HAI is urinary tract infection, and this is largely due to indwelling bladder catheters.[10,12,16] In more severe cases, urinary tract infections may lead to bacteraemia and cause a fatal outcome. Another group of infections that are common are surgical site infections.[10,16,17] According to the CDC definition, surgical wound infections can be incisional surgical wound infections or deep surgical infections.[15] Usually, during the operation, the patient is infected either by endogenous factors such as bacteria from their own skin or from exogenous factors such as the operating equipment or the ambient air.[10] Pneumonia is another HAI that occurs in diverse patient groups. One group is respiratory patients and another group is patients with decreased consciousness. Within geriatric care, influenza with a secondary bacterial pneumonia is common. Bacteraemia also occurs among HAIs and often occurs when the patient has a catheter in a vessel. Other common HAIs are gastroenteritis, sinusitis and meningitis.[10,12]

1.1.2 Infectious agents and antibiotic resistance

There are many different microorganisms involved in HAIs depending, for example, on patient populations, countries, and type of hospital departments.[10] The groups of microorganisms that cause HAIs are bacteria, viruses, fungi, and parasites.[10,12,18,19] Bacteria cause about 90% of HAIs and viruses cause about 5%.[12,18,20] Among the most commonly associated bacteria with HAIs are *Escherichia coli* (*E. coli*), *Staphylococcus aureus* (*S. aureus*), enterococci, *Klebsiella pneumoniae* (*K. pneumoniae*) and *Pseudomonas aeruginosa* (*P. aeruginosa*).[20,21] Some bacteria that are usually found on or in the body even in healthy people are part of the normal human microbiome.[12,18] These bacteria only cause disease when the immune system is compromised. Otherwise, the bacteria from the normal microbiome protect us from colonisation by pathogenic bacteria. There are also bacteria from the outside that are more virulent and can cause infections even in patients with normal immune function. *E. coli* is one example of a Gram-negative bacilli that belongs to the normal microbiome and colonises the gastrointestinal tract. It is also the most common cause of urinary tract infections. Other nosocomial infections caused by *E. coli* are for example surgical wound infections, and neonatal meningitis.[10,22,23] *K. pneumoniae* is a Gram-negative bacillus that can be found in the gastrointestinal tract well as the pharynx.[12,24] Pneumonia, urinary tract infections and bacteraemia can be caused by *K. pneumoniae.* Another bacterial species that is both commensal and a human pathogen is *S. aureus*.[25] It found in humans on the skin and in the nose, and it may cause wound infections, osteoarticular infections, and bacteraemia.[10,25] Enterococci are Gram-positive cocci found in the gastrointestinal tract.[26,27] Enterococci can cause urinary tract infections and post-surgery wound infections and are involved in intra-abdominal and intra-pelvic abscesses and can cause bacteraemia.[28] Examples of viruses that can spread HAIs are norovirus and rotavirus that cause gastroenteritis, and influenza virus which causes respiratory infection.[18,29] *Candida species* are fungal pathogens that can cause HAIs.[18]

Alexander Fleming discovered penicillin accidently in 1928.[30] [31,32] He noticed when he was going to clean a pile of forgotten Petri dishes in his lab, that in one of the Petri dishes, no *S. aureus* grew around a colony of mould. The mould, *Penicillum*, was later shown to contain a substance that could inhibit the growth of staphylcocci. This was the start of the development of penicillin, and it started to be manufactured for clinical use in 1941.

Antibiotic resistance is nothing new, and researchers have found genes encoding resistance to antibiotics such as β-lactams, tetracyclines and glycopeptides in bacteria in permafrost sediments.[33,34] Microorganisms have evolved systems to incapacitate harmful substances,[35] and this is in an expression of what Darwin described as natural selection. Under high antibiotic pressure, bacteria that are resistant to antibiotics are selected. The bacteria may have gained resistance through mutations in their genomes that gave them the advantage to cope with antibiotics. They can also share genetic material with each other through three different processes, namely conjugation, transformation, and transduction. In conjugation, the gene for resistance is transferred on a plasmid via pili between two bacteria. During transformation, the bacteria can pick up free DNA from the environment and insert it into their own genome. Bacteria can also transfer DNA to other bacteria by means of viruses (bacteriophages).[35]

There are a number of protective mechanisms that the bacteria have developed to cope with antimicrobial drugs.[36,37] One way is to produce enzymes that deactivate antibiotics, such as β-lactamases that break down β-lactam antibiotics. There are about 300 different types of β-lactamases identified,[36] and there are various ways of classifying the large number of β-lactamases. Giske et al. divided the β-lactamases into three main groups based on the enzyme activity of Extended Spectrum Beta-Lactamase (ESBL)-producing and carbapenemase-producing gram-negative bacteria.[38] Classic A ESBLs belong to the $ESBL_A$ group, miscellaneous ESBLs belongs to the $ESBL_M$ group and enzymes that have carbapenemase activity belongs to the $ESBL_{CARBA}$ group. Those bacteria harbouring ESBLs that have the greatest clinical significance are *E. coli* and *K. pneumoniae*.[39,40]

Two additional ways of surviving antibiotics in bacteria are to pump out the antimicrobials or to change the target of antimicrobials.[35,36] In order for antibiotics to be effective, they must accumulate to a certain concentration and must reach their target molecules. The three most common targets for different antimicrobials are the bacterial cell wall, bacterial DNA synthesis, and protein synthesis. In order to prevent antimicrobials from reaching a high concentration within the bacterial cell where protein synthesis occurs, the bacteria can increase the number of pumps in their cell wall, which helps to pump out the antibiotic. This is used, for example, to confer resistance to macrolides and tetracyclines. Both Gram-positive and Gram-negative bacteria, such as *S. aureus* and *E. coli* use such membrane pumps. Another way is to change the target area for antimicrobials. Examples of bacteria that use target modification are methicillin-resistant *S. aureus* (MRSA) and vancomycin-resistant enterococci (VRE).[35,36]

1.2 HOSPITAL ENVIRONMENT AND INFECTION TRANSMISSION

The hospital environment includes the premises for patient care, the equipment for patient care, and humans, including patients, staff, and visitors.[41] The patient's endogenous microbiome is the leading source of pathogens that cause HAIs. After that, the staff's hands contribute to cross infection in approximately 20–40% of the cases.[42] Surfaces close to the patient and frequently hand-touched areas represent the greatest risk for transmission of HAIs.[43,44] There has been no major scientific interest in studying the importance of cleaning the hospital environment for transmission of infections, even though many people are staying and working there.[29,45] It has been discussed whether the inanimate hospital environment poses any risk at all to the patient.[46] The low interest in hospital cleanliness might be due to the fact that there has been lack of standardised methodologies for assessing whether a surface is clean. In order to develop standardised methods to measure the degree of cleanliness in healthcare environments, experience has been gained from the food industry.[47] In the food industry, limit values of aerobic colony counts (ACC) have already been set up for the number of bacteria on food-processing equipment to be less than 5 colony forming units (CFU)/cm^2. These criteria have been modified to be better adapted to the hospital environment. When cleanliness of a surface is evaluated, an indicator organism that poses a high risk to the patient regardless of amount, for example *S.aureus,* is measured. The limit of indicator organisms in clinical settings should be <1 CFU/cm^2.[48-50] Then the amount of any bacteria on a surface is measured because it is known that large amounts of bacteria can pose a risk of infection to the patient. Recently, the total amount of

ACCs has been reduced to <2.5 CFU/cm^2 on a surface.[48,50] Risk areas to be measured in health care are areas that are often touched by the hands such as telephones and keyboards.[43,48,51]

An important part in infection transmission, is the ability of the bacteria to survive on inanimate surfaces.[52] There are many bacteria that can persist for a long time on different surfaces under dry conditions.[53-55] Gram-positive bacteria such as *S. aureus,* including MRSA, and *Enterococcus* spp., VRE, can survive for months on dry surfaces. This is also true for Gram-negative bacteria such as *E. coli*. Other factors that affect bacterial survival on surfaces are air humidity and temperature.[53,56,57] Most bacteria have a better persistence at higher humidity and lower temperatures such as 4-6 ^{o}C.

1.2.1 The radiology department and infection transmission based on previous studies

Most hospitals are comprised of a radiology department that is visited by a variety of patients every day, ranging from severely ill patients from intensive care units to healthy outpatients.[58] The environment with the different X-ray machines and other equipment constitutes a potential source of infection, although there has not been as much research about hygiene in radiology departments as in various other medical wards. Studies conducted in both radiology departments and other healthcare facilities indicate that inanimate surfaces are a possible source of infection. [53,59,60] Hygiene studies carried out in radiology departments have covered different areas. Mobile X-ray units have been studied as well as the cassettes used in the investigations.[61-63] Studies have also been carried out on radiographic markers,[64,65] lead aprons,[66] and ultrasound probes[67] concerning infection transmission and disinfection. In addition, more general studies have been conducted on different modalities in public and private radiology departments.[59,68]

Levin et al.[61] showed that mobile X-ray equipment used in the intensive care units, to take X-rays of the chest of the patient are a potential source of spread of MDR. In their study, observations were carried out on radiographers, who took X-rays of patients' chests in the intensive care department.

Observations were made of how the radiographers followed hygiene routines for washing and disinfecting their hands, wearing gloves, and storing x-ray cassettes in plastic bags. In the first phase of the study, observations were made without the radiographers being aware of it. Thereafter, observations were made after the radiographers received information about the importance of following hygiene routines, and finally observations were made during a five-month follow-up. In parallel, bacterial samples were taken from the mobile X-ray machine. There was a clear improvement in the compliance with hygiene routines among the radiographs after receiving information on hygiene. The study also showed that the number of bacteria decreased on the mobile X-ray machine. However, there was a decrease in compliance with hygiene routines in the follow-up period as well as an increased number of bacteria on the mobile X-ray machine. In two other studies by Fox and Harvey[62] and Kim et al.[63], bacteria were studied on X-ray cassettes. Fox and Harvey[62] found in their study that 38 out of 40 X-ray cassettes were contaminated with bacteria. The cassettes that were measured were used for mobile radiography, in accident and emergency patients and for inpatient use. One of the most commonly isolated bacteria was *S. aureus.* MRSA could not be identified in their study.

Kim et al.[63] specifically studied MRSA and methicillin-resistant S*taphylococcus haemolyticus* (MRSH) on X-ray cassettes used in the radiology department in a tertiary-care hospital. They found that 6 out of 37 X-ray cassettes were contaminated with MRSA and 19 out of 37 X-ray cassettes were contaminated with MRSH. Tugwell and Maddison[64] studied cleaning routines of radiographic markers (markers for left and right), and they also looked at the efficacy of alcohol gel and disinfectant wipes. It was found that 36% of technicians never washed their markers, 44% rarely did and 12% washed the markers every week. They found that no one washed their markers every day. Out of 25 samples, 92% were contaminated with different organisms such as *Staphylococcus epidermidis*, *S. aureus*, *Micrococcus* spp. and diphtheroids. No test for antibiotic resistance was performed in the study. The lowest number of bacteria was found on the markers that were cleaned weekly, and the most bacteria were found on the markers that were never or rarely cleaned. Finally, the concluded that there was no significant difference between disinfectants wipes and alcohol gel in decontaminating the markers, and both reduced bacterial load by about 80%. Hodges[65] also showed that radiographic markers could be a source for infection transmission in the radiology department and showed the importance of cleaning the markers. Lead rubber aprons were studied of Boyle and Strudwick[66] regarding infection transmission. They intended to study if there were measurable levels of microorganisms on lead rubber aprons that could cause cross infections and how cleaning with detergent and water affected the amounts of possible microorganisms. Bacterial samples were taken before and after cleaning from two different areas on the aprons, the underside of the shoulders and on the upper side of the front. Fifteen lead rubber aprons were included in the study and came from different areas within the radiology department. The results showed that all aprons were contaminated with bacteria before cleaning such as *S. aureus*, *Bacillus* spp. and diphtheroides, but no MRSA were found. After cleaning, the CFU were reduced on most of the lead rubber aprons. The location underneath the shoulders measured higher numbers of CFU/cm^2 than the upper side of the front, both before and after cleaning. The authors believe that this might be because the area underneath the shoulders is handled more, but it might also be due to the different materials on the outside and inside of the lead rubber apron. The least contaminated lead rubber aprons were measured from the operating theatre and the Special Care Baby Unit, which according to the authors might be because these departments pay a greater attention to infection control.

Ultrasound equipment is in close contact with the patient and can be a source of cross infection, which was studied by Sykes et al.[67] Bacterial samples were taken from five ultrasound machines, two of which were used for invasive procedures and three for non-invasive procedures. In total 302 samples were taken from four areas (probe, probe holder, keyboard and gel) of the five ultrasound machines. They found that 64.5 % of the samples were contaminated with skin/environmental organisms and, 7.7 % of the samples were contaminated with potential pathogens such as *S. aureus, Enterococcus faecium, and E. coli* depending on the site of detection. In 27.8 % of the samples no growth was found. The highest number of potential pathogens was found on non-invasive equipment. According to the authors, this could have two potential explanations. First, there might be poor compliance with decontamination protocols, and second, the level of decontamination might be much higher for invasive equipment. The authors finally concluded on the importance of thorough cleaning of the ultrasound equipment to prevent the spread of infection, which is also supported by earlier studies on ultrasound equipment.[69,70] In a study of Eze, Chiegwu and Okeji[59], X-ray equipment (X-ray couch, chest stand, tube head handle, exposure bottom, control console, X-ray cassettes and anatomical markers) in public and private radiology departments were measured. A total of 200 samples were taken, including 100 samples from the public radiology departments and 100 from the private radiology department. In total, 182 samples out of 200 showed bacterial growth, and 28 samples had no growth. More samples (96/100) showed bacterial growth from the public radiology departments, compared to the private radiology departments (56/100). In both public and private radiology departments, X-ray cassettes were the most contaminated surfaces, and *S. aureus* was the most commonly isolated bacteria similar to the study of Fox and Harvey[62]. A directed study regarding contamination of MRSA in a radiology department was performed by Shelly et al.[68] In their study 125 bacterial samples were taken from different surfaces such as floors, pump injectors, magnetic resonance imaging (MRI) coils, and X-ray cassettes. Only one sample out of 125 was positive for MRSA, which was a sample from the surface of the bore of the MRI unit.

1.3 HEALTHCARE PROFESSIONALS' ATTITUDE AND ADHERENCE WITH HYGIENE GUIDELINES

The fields of microbiology and epidemiology are the areas where knowledge about spread of diseases and its pathology where gathered in the work for preventing HAI and creating infection prevention and control protocols in healthcare.[71] Recently, more attention has also been paid to the fact that most infections are endemic and the importance of hygiene routines in the care of patients to prevent cross infections.

1.3.1 Hand hygiene

To reduce and prevent the spread of HAIs, adherence with hygiene guidelines is of the greatest importance.[72,73] The most important of all hygiene routines is hand hygiene, which is also the most simple and effective in preventing HAIs.[74] [75] The microorganisms present on the skin can be divided into two groups, including those that belong to the resident flora and are difficult to wash away, and the transient flora consisting of contaminants that can be removed by hand washing and disinfection.[74-76] The resident flora is found under the superficial cells of the stratum corneum, and the transient flora is located on the surface of the skin or beneath the superficial cells. It is the transient flora that causes most HAIs through cross-transmission when poor hand hygiene is used.[75,76] The microbial composition of the transient microbiome can vary widely in size and content due to surrounding factors.[76] It is not uncommon for healthcare professionals who have been in contact with patients colonised with, for example, MRSA, VRE, or *Clostridioides difficile* to be the carrier of these bacteria on their hands.[75] How long the transient flora survives on the hands cannot be specified because this depends on environmental factors, but a common estimation is 2–60 minutes.[76-78]

Hand hygiene has been the basis for preventing cross infections for over 150 years, as exemplified by the efforts of Ignaz Semmelweis and Florence Nightingale.[75,79] Nevertheless, a large number of healthcare professionals do not wash their hands according to the guidelines.[73-75,80,81] Less than 50% of healthcare professionals comply with the guidelines for hand hygiene even in high-income countries.[74,75] The guidelines for hand hygiene other than hand washing and disinfection also include the use of gloves, which if properly used can reduce the risk of cross infection.[82,83] The knowledge and the adherence with glove use is relatively good among healthcare professionals.[83] In the study of Flores and Pevalin[84] the adherence with glove use was 92% and the overall hand hygiene adherence was 64%.[84] However, that study also showed an overuse of gloves by 46%. The healthcare professionals used gloves when not indicated and they did not always change gloves between each patient. Similar studies also show that improper glove use contributes to poor adherence with hand hygiene.[85-87]

1.3.2 Barriers and opportunities to following hygiene guidelines

There are many reasons why healthcare professionals do not follow the basic hygiene guidelines. As for hand hygiene, one reason mentioned is that gloves replace other hand hygiene routines.[74,77] Another reason is that hygiene agents irritates the skin, which has also been shown scientifically.[88] Additional causes that have been mentioned are that proper hygiene is too time consuming and, interrupts patient care, that staff are ignorant of the guidelines, that facilities are not appropriately placed, and that patient work involves high workload and understaffing.[74,77,89,90] It has also been found that the lack of scientific information about the benefits for patients from following the guidelines, has influenced the staff's attitudes. The staff have therefore not understood the importance of adopting hygiene guidelines.[74,89] Aspects that motivate staff to follow basic hygiene guidelines according to medically responsible nurses in community care in a study by Lindh, Kihlgren, and Perseius[91] include resources, management, staff and external factors.[91] It is important that there are resources in terms of time, equipment and training regarding hygiene guidelines. The training of the staff is to be given by a specialist nurse in hygiene, which better motivates staff to follow the hygiene routines. There should also be time for discussion and reflection on hygiene issues. Another important factor is support and commitment from management. In the study of Lindh, Kihlgren, and Perseius[91], it was found if the management does not care about hygiene issues, neither will the staff. There must also be individual participation by the employees in combination with teamwork, where the individual efforts will be visible. The media can also influence adherence with hygiene routines, and when reporting on outbreaks of endemics or pandemics, the procedures for hand hygiene tend to be better followed.[91]

Education has proven to be important for adherence with hygiene routines, as well as the need for clear guidelines.[92,93] Even if these are available, staff do not always follow the guidelines. Different theories of human behaviour have been studied in relation to hygiene adherence, and an initial study was conducted by researchers in the Study on the Efficacy of Nosocomial Infection Control on social power linked to infection control.[71,94,95] Six concepts related to power were set up in the study, namely coercive, reward, legitimate, expert, referent, and informational. A total of 7,046 nurses were then questioned about what kind of social power best explained the adherence to hygiene routines among hospital personnel. The results showed that expert and informational power had the greatest impact on adherence to guidelines among the nurses. It was also found that the staff have knowledge and education about hygiene, but that they apply their own ideas that do not always follow the guidelines and that they rationalise their actions afterwards.[96]The nurses had no insight that their behaviour differed from the guidelines. In order to understand what makes the staff follow guidelines, more studies are needed on how motivation affects behaviour.[94]

2 AIMS OF THE THESIS

The overall purpose of this thesis was to study if the modalities of CT and MRI might be a source for cross infections as well as to study the staff's adherence with hygiene guidelines.

Specific aims:

- The purpose of Study I was to identify hand-touched surfaces inside and outside the CT and MRI examination rooms that might be more prone to bacterial contamination. We also wanted to determine if MRSA could be detected in CT and MRI examination rooms, and also if *E. coli* and *K. pneumoniae* producing ESBL or carbapenemases were detectable. The study also aimed to identify differences between public and private radiology departments in terms of bacterial contamination.

- The purpose of Study II was to investigate the staff's adherence to hygiene guidelines when working with CT and MRI and the managers' attitudes to hygiene at the radiology department. A secondary aim was to assess differences in adherence with hygiene guidelines between public and private radiology departments.

3 MATERIAL AND METHODS

3.1 STUDY DESIGN

3.1.1 Study I

Six operations managers of six public radiology departments and six private radiology departments were contacted to obtain their permission to perform the study. Two of the private radiology departments declined to participate. The areas for bacterial sampling in the CT and MRI examination rooms were selected according to the frequency of hand-touched areas (Table 1). Indicator organisms of relevance and the size of the sampling area were decided on after a literature review. As indicator organisms, MRSA, ESBL-producing Enterobacteriaceae (EPE) and carbapenemase-producing Enterobacteriaceae (CPE) were used. Other microorganisms were only characterised by Gram staining. The measurement area was 100 cm^2 whenever possible. The exceptions were the alarm control and the headphones in the MRI examination room. The alarm control was swabbed in its entirety and the inside of one headphone was swabbed, then the area was calculated retrospectively. One sample was taken from each selected surface (Table 1).

Table 1. Sampling areas of the CT and MRI examination rooms.

Sampled hand touched areas of the CT- examination room	Sampled hand touched areas of the MRI- examination room
Pillow in the head support	*Headphones*
Head support	*Alarm control/buzzer (held in the patient’s hand during the examination)*
The center of the examination table	*Skull coil*
Side of the examination table	*Knee coil*
Gantry control panels	*Side of the MRI tunnel (around 10 cm from the bore)*
Control panels of contrast injector	*Gantry control panels*
Support pillow	*Support pillow*
Workspace of the medicine trolley (a wagon used for intravenous cannulation and administration of contrast media and medicine)	*Workspace of the medicine trolley (a wagon used for intravenous cannulation and administration of contrast media and medicine)*
Chair of the patient changing room	*Side of the examination table*
Keyboard in the control room	*Keyboard in the control room*

3.1.2 Study II

Study II was a continuation of Study I, and the same six public radiology departments and four private radiology departments participated. Two different questionnaires were developed based on the basic hygiene guidelines.[97] The questionnaires contained mostly closed questions, but also some open questions. One of the questionnaires addressed the staff that worked with CT and MRI in public and private radiology departments. The inclusion criteria for that survey were radiologists, radiographers and assistant nurses who worked with CT and/or MRI. In the questionnaire, the staff answered questions about demographic data, how they themselves followed the basic hygiene routines, and how they estimated their own and their department's commitment to hygiene issues. The second questionnaire addressed the managers, where they had to fill in demographic data and answer questions about their own knowledge of basic hygiene guidelines, how they prioritised hygiene issues in their department, and what they thought were the reasons why hygiene guidelines were not followed. For the second questionnaire, managers who were in contact with CT and/or MRI were included. Before the study began, two pilot studies were first performed in a small group without connection to radiology and then in a radiology department.[98]

3.2 DATA COLLECTION METHODS

3.2.1 Study I

The bacterial samples were taken with flocked nylon swabs (Copan Liquid Amies Elution Swab (Eswab)).[99,100] In order for bacterial measurements to reflect reality as much as possible, the samples were taken in the middle of the day during full activity. Before the samples were taken, the staff cleaned the equipment as usual between patients. Then the same person took all samples throughout the study, and hands were disinfected before sampling. The flocked nylon swabs were pre-wet in the Liquid Amies medium before sampling, then a 100 cm^2 surface was swabbed in a rotating zigzag pattern.[101] To mark the sampling area, a template was used so that the surface would be equal for all samples. The headphones and the alarm controls were swabbed separately, inside of headphone and the whole alarm control. After each sampling, the swab was placed in the Liquid Amies medium for transport to the microbiology laboratory and subsequent cultivation. Each test tube was vortexed for one minute before a 100µl sample was taken for cultivation on different agar plates, including one chocolate agar plate and selective agars for extended-spectrum beta-lactamase producing Enterobacteriaceae (EPE), carbapenemase-producing Enterobacteriaceae (CPE), and MRSA.[102] Then the plates were incubated at 37^{o}C in 5% carbon dioxide (chocolate agar) or air for 48 hours.

3.2.2 Study II

A total of 250 questionnaires were distributed to the ten different radiology departments during the autumn of 2016. One person in the research group personally distributed the surveys to the staff at the radiology departments and collected the completed surveys. Surveys were also handed out to the clinical teachers at the various radiology departments, who also distributed them to the staff. The clinical teachers reminded staff to fill in the questionnaires in order to increase the response rate and then collected the completed questionnaires.

3.3 DATA ANALYSIS

3.3.1 Study I

When the agar plates were finished incubating, the numbers of CFU were counted on each plate as the measure of viable bacterial contamination.[64] The data were transferred to an Excel spread sheet. Matrix-assisted laser desorption ionisation time of flight (MALDI-TOF) was used to identify Gram-negative bacteria.[103] The convention for reporting surface contamination was the number of ACCs as CFU/cm^2. As a limit to assess an area as contaminated < 2.5 CFU/cm^2 has been used.[48,50] Thomsen's formula was used to calculate the ellipse-shaped area of the headphones and the alarm control. For statistical analysis of data regarding differences between bacterial contamination of different surfaces, as well as differences between public and private radiology departments, a two-tailed unpaired t-test was used with a 95% confidence interval. Differences were considered significant for $p<0.05$. The Statistical Package for Social Sciences (SPSS v.26; IBM, New York, USA) was used for creating all of the diagrams.

3.3.2 Study II

Data from closed questions were encoded and transferred to Excel Office 365, and data from open questions were transferred to Word Office 365. The collected data from the closed questions were summarised in frequency tables and comparisons between groups regarding categorical data were analysed using Fisher´s exact test in GraphPad 7 (GraphPad Software, San Diego, USA) for 2 × 2 contingency tables and using the Free Statistics Calculators, version 4.0 (https://www.danielsoper.com/statcalc/calculator.aspx?id=58 (accessed: 14-05-2020)) for 2 × 3 contingency tables. Independent t-tests were performed in SPSS to compare continuous variables. The significance level was set at $p<0.05$. The content of the open questions was analysed with inspiration from manifest qualitative and quantitative content analysis.[104-106] Under each open question, the respondents' answers was written down and highlighted by content. It was difficult to perform a traditional qualitative content analysis because, most of the respondents answered the question with single words, but it was possible to group the words into different categories and present them individually under each question. The data from the open questions were also presented with descriptive statistics in the form of bar charts.

3.4 ETHICAL CONSIDERATIONS

Both Study I and II were considered and approved by the Regional Ethics Committee in Stockholm (record 2015/2288-31).

Participation in the survey was entirely voluntary and the surveys were anonymous. All collected material was treated confidentially.

4 RESULTS

4.1 STUDY I

4.1.1 Bacteria found inside and outside the CT- and MRI examination rooms on inanimate surfaces

In the bacterial microbiota of both CT- and MRI examination rooms, Gram-positive bacteria dominated, whether it was a public or private radiology department. Gram-negative species were only identified on three occasions. No indicator organisms such as MRSA, EPE, or CPE were found in any of the investigated radiology departments.

The results showed that 3 of 10 measured surfaces in the public CT examination rooms had a median value >2.5 CFU/cm^2 and in the private CT examination rooms 6 of 10 surfaces had a median value >2.5 CFU/cm^2 (Fig. 1). The most contaminated surfaces inside and outside the CT examination rooms were the same in both the public and the private radiology departments namely the sides of the examination table, keyboards, chairs in the patient changing rooms and pillows on the head support (Fig. 1). The highest measured values of CFU/cm^2 were 20 on the sides of the examination tables, 11 on the keyboards and 10 on the chairs in the patient changing rooms and the pillows of the head supports. In the public CT radiology departments, high values of 10 CFU/cm^2 were also measured on the control panels on the contrast injector. In the private radiology departments, CT examination rooms high values of CFU/cm^2 were also measured at the centre of the examination table (10 CFU/cm$^{2)}$ and the support pillow (8 CFU/cm^2). The least contaminated surfaces were found on the medicine trolley in both the public and private CT examination rooms, where cultures were negative (0 CFU/cm^2) on some trolleys (Fig. 1). A low number of CFU was also found on the centre of the examination table in the public radiology departments´ CT rooms. In 1 out of 6 rooms, the cultures were negative (0 CFU/cm^2) (Fig. 1). There was a significant difference in both public and private radiology departments, between the medicine trolley and the keyboard in the control room ($p = 0.01$ and $p = 0.02$, respectively).

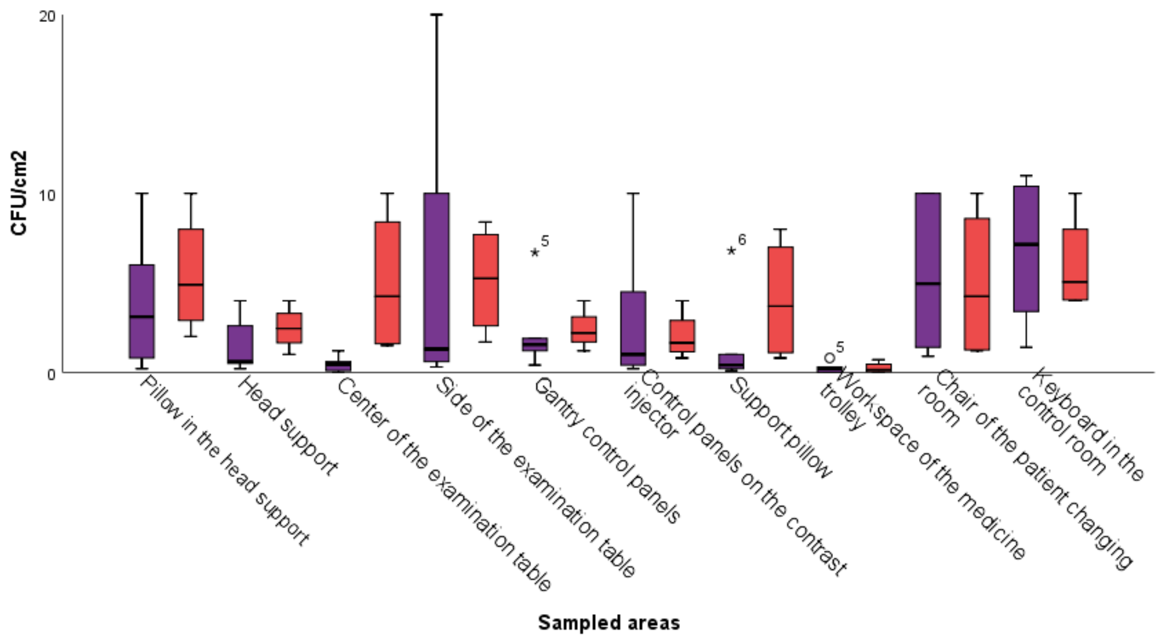

Fig. 1 Number of CFU/cm² of Gram-positive bacteria on different hand-touched surfaces inside and outside the CT examination rooms of the public and private radiology departments. The purple boxes represent public radiology departments and the red boxes represent private radiology departments.

Regarding the MRI examination rooms, public MRIs had 6 of 10 surfaces with a median value >2.5 CFU/cm² and for private MRI examination rooms 8 of 10 surfaces had a median value >2.5 CFU/cm² (Fig. 2). In the MRI examination rooms in both the public and private radiology departments, the headphones, the support pillows and the alarm controls/buzzers were among the most contaminated areas (Fig. 2). The highest measured value of CFU/cm² was 169 on the headphones and 30 on the support pillow (Fig. 2). For the alarm control/buzzer, the highest number of CFU/cm² was 13 (Fig. 2). The keyboards, the sides of the examination tables and the gantry control panels were also areas where the median values were more than 2.5 CFU/cm² (Fig. 2). In the MRI examination room in both the public and private MRI radiology departments, the least contaminated surfaces were on the medicine trolleys, with a range of 0.1–4 CFU/cm² and the sides of the MRI tunnel, with a range of 0–1.4 CFU/cm² (Fig. 2). In both the public and the private MRI departments there was a significant difference between the least contaminated workspace on the medicine trolley and the alarm control/buzzer ($p = 0.03$ and $p = 0.005$, respectively).

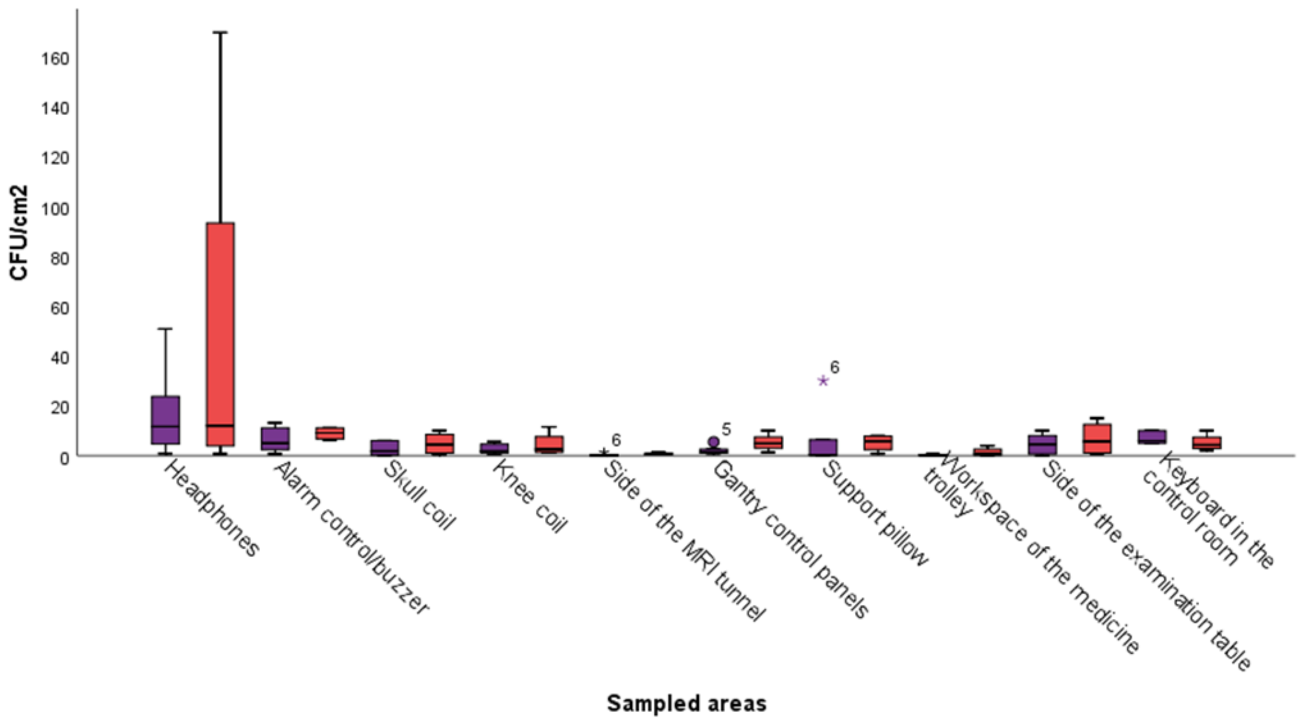

Fig. 2 Number of CFU/cm² of Gram-positive bacteria on different hand-touched surfaces inside and outside the MRI examination room of the public and private radiology departments. The purple boxes represent public radiology departments and the red boxes represent private radiology departments.

4.1.2 Differences in the number of CFU/cm² in public and private CT and MRI examination rooms

The numbers of CFU/cm² for the ten measured surfaces in each public and private radiology department, with respect to the inside and outside of the CT and MRI examination rooms are, shown in Figures. 3 and 4. One out of six public radiology departments' CT examination rooms had a higher median value (3.4 CFU/cm²) than the limit value of 2.5 CFU/cm² (Fig. 3). The lowest median value of was 0.6 CFU/cm², which was observed in two of the public radiology departments' CT examination rooms. Among the private radiology departments' CT examination rooms, a median value higher than 2.5 CFU/cm² was seen in 3 out of 4 radiology departments, having values ranging between 2.8 and 5 CFU/cm².

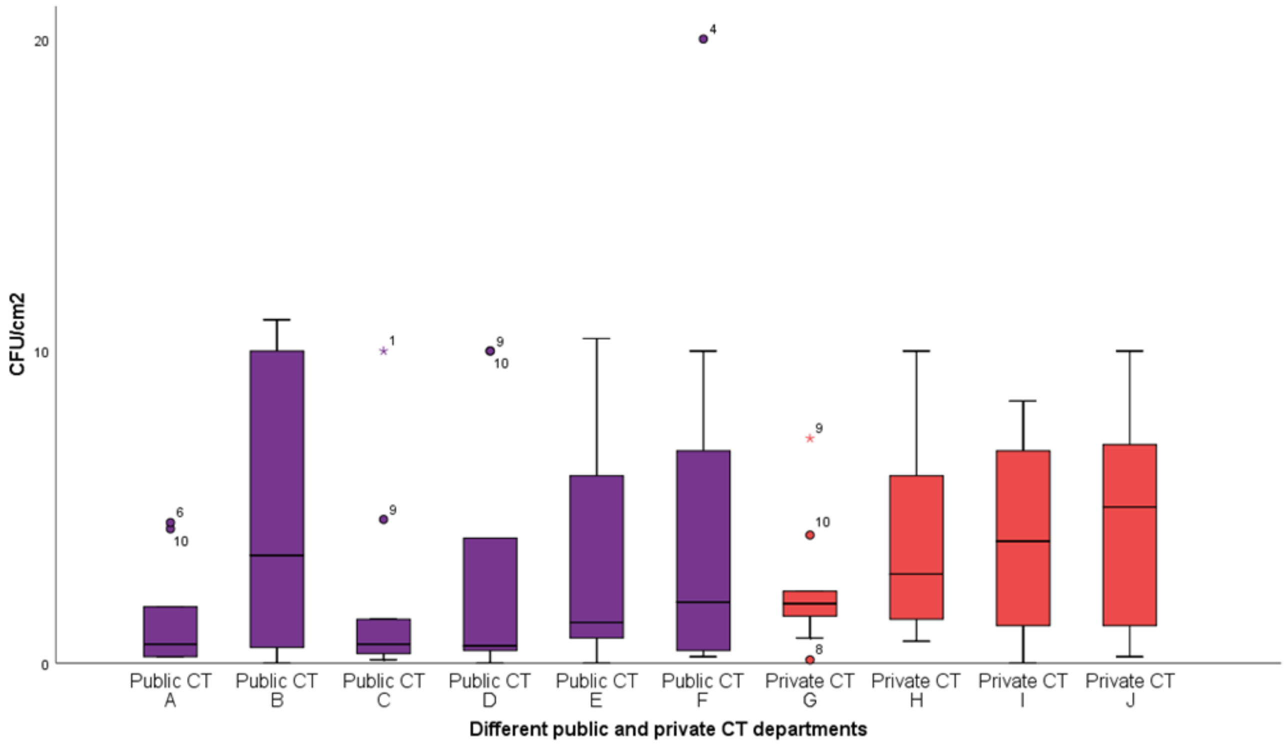

Fig.3 The numbers of CFU/cm^2 for all measured hand-touched surfaces inside and outside the CT examination room for each public- and private radiology departments.

Among the public MRI examination rooms, 3 out of 6 had a higher median value than 2.5 CFU/cm^2, ranging between 3.1 and 5.2 (Fig. 4). Out of the four private MRI radiology departments, two had a median value higher than 2.5 CFU/cm^2, ranging between 5.1 and 8.5 (Fig. 4). The lowest median value was observed for the medicine trolley, with a range of 0.1–4 CFU/cm^2, and the side of the MRI tunnel, with a range of 0–1.4 CFU/cm^2 (Fig. 4). No statistically significant difference was found between public and private radiology departments in the number of CFU/cm^2 inside and outside the CT and MRI examination rooms.

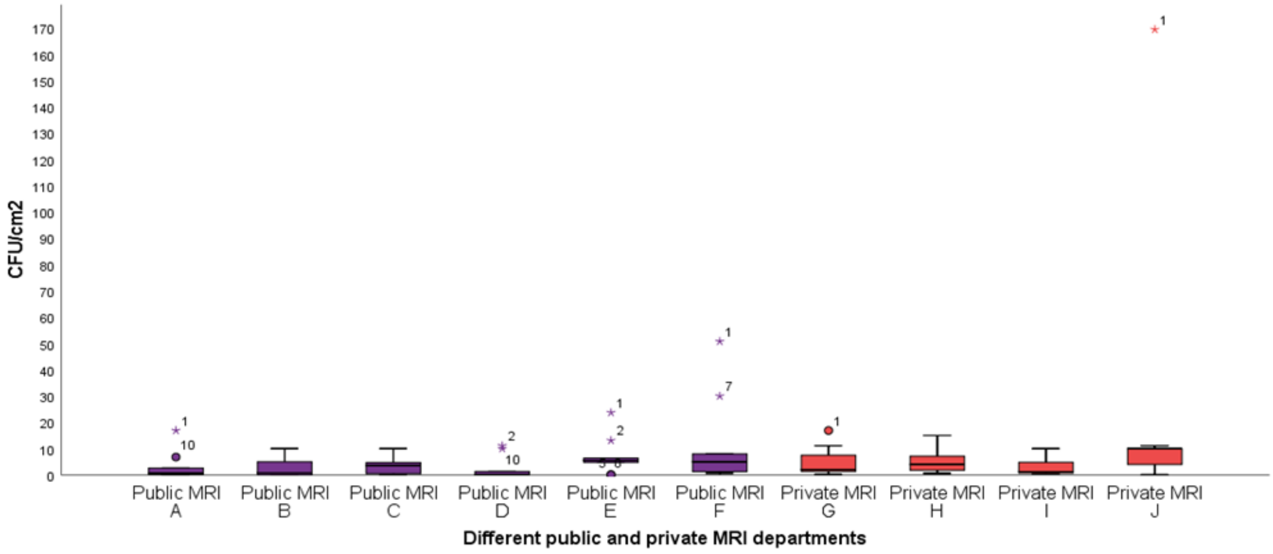

Figure 4. The numbers of CFU/cm^2 for all measured hand-touched surfaces inside and outside the MRI examination room for each public-and private radiology departments.

4.2 STUDY II

The response rate for the questionnaire was 163 respondents out of 250 distributed. Among the respondents, 141 were staff working with CT and/or MRI in public or private radiology departments and 22 were managers. The proportion of women and men working with CT and MRI were 111 (79%) and 30 (21%), respectively. In the group of managers, 17 (77%) were women and 5 (23%) were men. The median age for women and men working with CT and MRI was 46 (range 22–71) years. For managers the median age was 52 (range 28–69years). The median of years in the profession was 13 (range 1–46) years for staff working with CT and MRI. The median years as a manager were 4.5 (range 0.15–20) years.

4.2.1 Education and adherence to basic hygiene guidelines among staff and managers

The majority of the staff in both public CT and MRI (87/105, 83 %) and private CT and MRI (25/33, 76%) had received hygiene training during their undergraduate education. They had also received training in hygiene guidelines at their current workplace and did not feel any need for more education at this time. There were no significant differences between men and women concerning education and knowledge about hygiene. The managers in both public and private radiology departments prioritised hygiene training for the staff and had also undergone hygiene training themselves and were aware of what was included in the hygiene guidelines. Most of the managers in public radiology departments (12/17, 70%) and private radiology departments (4/5, 80%) thought that the hygiene guidelines were followed to some extent.

In general, adherence to basic hygiene guidelines was good among the staff both within public and private CT and MRI. With regard to the wearing of rings, bracelets and nail polish in patient-related work, a significant difference was found between public and private CT and MRI. In public CT and MRI, 101/103 (98%) of the staff responded that they did not wear rings, bracelets or nail polish in patient-related work, while the corresponding figure for staff working in private CT and MRI was 26/33 (79%) ($p = 0.007$). Another significant difference between staff working in public and private radiology departments was the use of plastic aprons in patient-related work. In public CT and MRI, 106 of 107 (99%) reported that they always / frequently used plastic aprons, while the corresponding number of staff in private CT and MRI was 16/33 (48%) ($p < 0.001$). There was no significant difference between women and men.

4.2.2 The radiology department and hygiene routines

The results showed some significant differences between how X-ray equipment was cleaned within the public radiology departments' CT and MRI examination rooms compared to the private radiology departments' CT and MRI examination rooms. There was a significant difference ($p = 0.003$) between whether the examination table was disinfected between each patient. Among the public radiology departments, 77 of 98 (78%) staff responded that they always disinfected the table between each patient compared with 3 of 8 (38%) staff in private radiology departments. A significant difference ($p = 0.001$) was also found regarding how support pillows were cleaned between each patient between the public and private CT and MRI radiology departments. For the public CT and MRI, 71 of 103 (69%) staff answered yes/always and only 1 of 103 (1%) answered sometimes/rarely or never, while the corresponding figures for private radiology departments were 6 of 21 (29%) and 7 of 21 (33%), respectively. It was also possible to see a significant difference ($p = 0.001$) between how interchangeable parts such as headrests and various coils were cleaned by the staff between patients in public and private radiology departments' CT and MRI facilities. In public CT and MRI, 65 of 106 (61%) staff indicated that they always disinfected replaceable parts and only 9 of 106 (8%) answered sometimes/rarely or never. The corresponding figures in private CT and MRI were 1 of 18 (6%) and 10 of 18 (56%), respectively. In general, the staff in both the public and private radiology departments' CT and MRI facilities thought that the hygiene standard was good or quite good. The study also allowed staff to estimate their own adherence with basic hygiene routines on a scale of 1 to 10 (with 1 = shortcomings in meeting the hygiene guidelines and 10 = following the guidelines to the best of their ability), and a significant difference ($p = 0.005$) was seen between public and private employees. No staff in either public or private radiology departments’ CT and MRI examination rooms reported scores of 1–3. In the public radiology departments’ CT and MRI, 25 of 102 (24%) staff estimated their adherence at 4–7 and 77 of 102 (75%) estimated their adherence at 8–10. Corresponding figures for the staff of the private radiology department's CT and MRI were 17 of 33 (52%) at 4–7 and 16 of 33 (48%) at 8–10. There was no significant difference between men and women concerning following hygiene guidelines in the radiology departments.

4.2.3 Reasons why basic hygiene practices are not followed according to staff working with CT and MRI

In the questionnaire for X-ray staff there was only one open question, “What is the main reason for you to not follow the basic hygiene guidelines?” The question was answered by 101 persons out of 141. Three of the 101 answers were unreadable. The results are shown as the frequency (percentage) with which a theme was mentioned (Fig. 5).

4.2.3.1 Stress and emergency situations

Stress was the main reason not to follow the basic hygiene procedures according to 26 % of the respondents. High patient flow triggered stress and it also emerged that colleagues stressed each other to abstain from following the guidelines for basic hygiene. It was felt to be too difficult to be accurate with hygiene when it was stressful.

“Stress and hard patient pressure.”

Another strong reason according to 25 % of the respondent’s was emergency situations. This could be cardiac arrest situations or similar situations when the patient's life was in danger and when every second was important to save the patient's life.

“Emergency situations where the patient's life is in danger”

4.2.3.2 Time aspects

Time was another reason mentioned by 18 % of the respondents. There was not enough time to follow basic hygiene practices between each patient, and there was not enough time to disinfect hands between each patient, especially not if you were going to put on the gloves after disinfection, because it takes time to let hands dry. There was too much to do in relation to the time it took to perform the hygiene tasks.

“Too much to do there is no time.”

4.2.3.3 Special working conditions

Special working conditions were mentioned as a reason for not following hygiene guidelines by 6% of the respondents. Some thought it was too cold in the facilities and therefore wore long sleeves in patient-oriented work. Others found it difficult to do intravenous cannulation with gloves. Others thought that it was too hot and uncomfortable to wear plastic aprons, when working in close contact with the patient even though it is part of the guidelines for basic hygiene.

"When I put a needle in the arm of the patient, I prefer to do it without gloves."

4.2.3.4 Laziness

Laziness and carelessness were mentioned by 4 % of the respondents.

"Forget, carelessness."

4.2.3.5 Other

Other reasons for not following the basic hygiene practices that the respondents mentioned were in the style of not being needed, peer pressure, difficult in cleaning the equipment, and that they only had healthy patients.

"It is clean enough in our department"

"Because the patients who come to us are mostly healthy and come clean from home"

4.2.3.6 There is no reason

A group of 15 % of the respondents thought that there were no reasons, not to follow the basic hygiene routines.

"Basic hygiene procedures must be followed. "

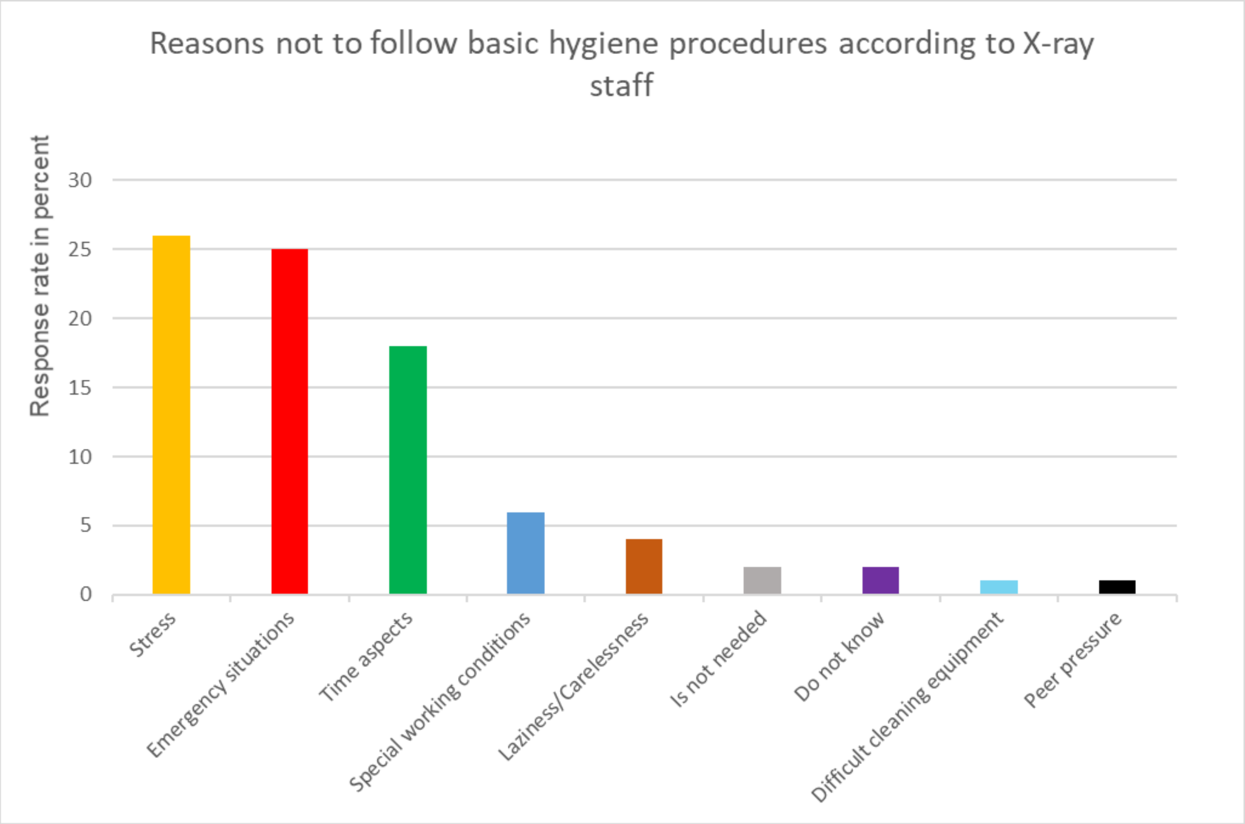

Fig.5 Reasons for why staff do not follow hygiene guidelines when working with CT and MRI in public and private radiology departments.

4.2.4 Reasons why basic hygiene practices are not followed, according to managers

The managers answered two open questions of which the first was: “What are the reasons that staff do not follow basic hygiene guidelines according to you?” The question was answered by all managers 22 out of 22 (Fig. 6).

4.2.4.1 Stress and time aspects

Stress was answered by 24 % of the managers. The workload is high with many patients and there are not enough staff to do the work.

“I think it is stress. “

Time aspects were mentioned by 18% of the respondents. When the patient flow is high and time is insufficient, one tries to take shortcuts and hygiene is not prioritised.

“Indicates that you do cannot take shortcuts”

4.2.4.2 The organisation

According to 20% of the respondents, the organisation in the radiology department had an influence on the adherence to the basic hygiene guidelines. It is important that there is someone in the radiology department who is responsible for the follow-up of hygiene guidelines. Otherwise it might be difficult to implement hygiene routines in the radiology department. The responsible radiographer must also be able to educate the staff continuously on hygiene issues. There is also a need to continually allocate time to the X-ray department for the training of staff in hygiene.

"There must be clear guidelines and responsible hygiene nurses who are well-informed on this."

4.2.4.3 Laziness and lack of knowledge

Laziness and carelessness were mentioned by 20 % of the respondents. The managers did not think the staff were thinking about the consequences of not following the hygiene guidelines, and they felt that some of the staff just forget about it.

"Carelessness is the problem."

Lack of knowledge among staff for not following hygiene guidelines, was answered by 15% of the respondents.

"Ignorance."

4.2.4.4 Special working conditions

The respondents also mentioned special working conditions in 3% of the answers, and it was mentioned that the staff are reluctant to disinfect their hands before wearing gloves.

"There is some non-adherence to disinfecting hands before putting on gloves"

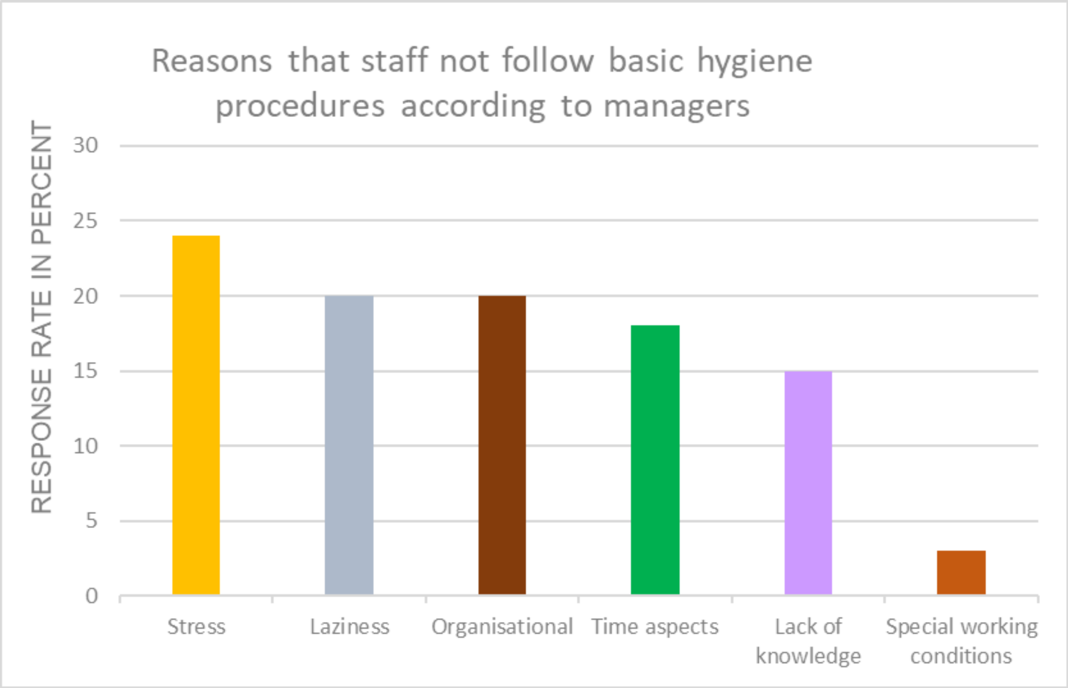

Fig.6 Different reasons why staff do not follow hygiene guidelines when working with CT and MRI according to their managers in public and private radiology departments.

4.2.5 Most common hygiene guidelines not followed by staff

The second open question for managers was:" What basic hygiene guidelines are not followed by staff according to you?" The question was answered by 17 out of 22 respondents (Fig.7). One of the 17 answers was unreadable.

4.2.5.1 Hand hygiene

Hand hygiene was what 33% of the respondents thought the staff were most careless with. They pointed out the incorrect use of gloves in contact with patients. Gloves should be used if there is a risk of contaminating the hands with body fluids, but some of the staff used gloves regardless of the situation or patient according to the respondents. Instead of using so many gloves, the staff should disinfect their hands. The respondents also thought that the staff needed to learn how to disinfect their hands properly.

"The correct use of gloves."

4.2.5.2 Cleaning the equipment

Cleaning the equipment was mentioned by 28% of the respondents. Because many radiology departments used paper sheets on their examination tables, the staff did not wipe the examination table with disinfectant between each patient. Instead they put new paper sheets on the examination tables. Other areas that the managers thought were poorly cleaned were the keyboards and other hand-touched areas. Someone also mentioned that the MR tube probably was not cleaned often.

"Forget to disinfect the desktop, keyboard, hand touched surfaces, etc."

4.2.5.3 Dress policy

17% of the respondents did not think that the staff followed the dress rules.

"Our clothing policy does not work"

4.2.5.4 Hair and nails

It was also obvious among the respondents that the staff did not tie up long hair 11% and that some of the staff uses nail polish (6%).

"Tell them to tie up their hair."

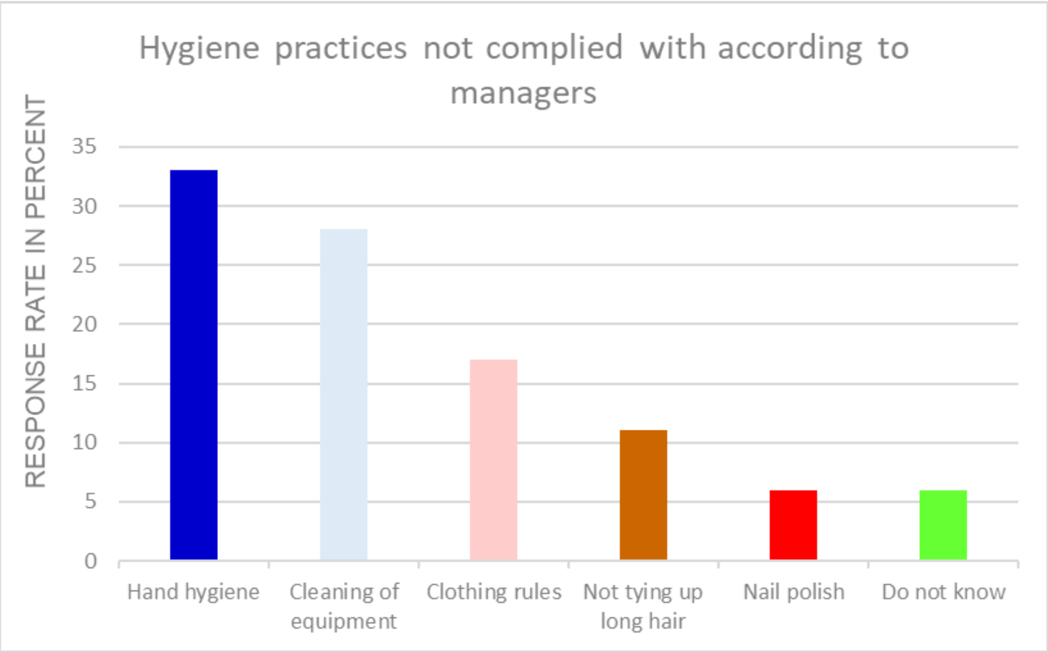

Fig.7 Different hygiene guidelines not followed by staff working with CT and MRI according to the managers.

5 DISCUSSION

5.1 BACTERIAL FINDINGS IN CT AND MRI EXAMINATION ROOMS

Like the vast majority of previous studies carried out in both radiology departments and healthcare departments[46,52,58,59,62,64-66,107,108], the results of our study also demonstrate bacterial contamination on a variety of hand-touched surfaces that could be a potential source for HAI. No indicator organisms such as MRSA were identified from the sampled surfaces, which might mean that there are well-established cleaning routines between patients and that the guidelines are followed.[109] A study of this kind also has its limitations, because it was only an extremely small area that was measured in relation to the actual object size, thus potentially allowing indicator organisms to be missed. In a study by Kim et al.[63] MRSA was found on 6 out of 37 X-ray cassettes and in their study, they sampled the entire patient-contacting surface and not just a part of it. Another reason that no indicator organism were identified could be that the staff knew that bacterial measurements would be carried out during the day, which could have affected them to clean more properly than they normally do.[64] In addition, there is the fact that the rate of MRSA is quite low in Sweden in general compared with other countries.[110,111] The main findings in this study was the predominance of gram-positive bacteria, and only a few CFU of gram-negative bacteria were detected. This observation is in line with a another study that also showed that gram-positive bacteria were detected at a higher frequency than gram-negative bacteria on inanimate surfaces.[112] A number of surfaces had more CFU/cm^2 than the limit value of <2.5 CFU/cm^2.[48] However, it is still not certain what this means for the individual patient who comes to the radiology department, and it is still debatable whether inanimate surfaces contribute to HAIs and what the effectiveness is of surface disinfection in relation to reducing HAIs.[113,114] Within this framework, it has also been discussed whether disinfectants play a role in increasing allergies among hospital staff[115] and what the environmental impact is of disposing of disinfectants in waste water.[116] However, most studies point to the importance of a good hygienic standard for reducing the transmission of HAIs in health care.[29,117-119] and hand-touched surfaces seems to be of extra importance in cross transmission.[120,121]

5.2 BACTERIAL CONTAMINATION OF DIFFERENT SURFACES IN THE CT AND MRI EXAMINATION ROOMS

The aim of the study was also to determine if there were hand-touched surfaces in the CT and MRI examination rooms with higher bacterial contamination. Keyboards were among the most contaminated surfaces for both CT and MRI as well as in public and private radiology departments. This is in line with what has been found in other studies.[122,123] In one study, 100 keyboards were examined, 95 of which were contaminated with bacteria.[124] This shows the importance of following proper hand hygiene guidelines because keyboards are constantly being touched by the hands of the healthcare workers.[125,126] In a study on keyboards and computer mice role in the spread of MRSA, it was shown that keyboards were touched 34.5 times/hour after patient/environmental contact, but hand hygiene was only preformed 3.2 times/hour before contact with the keyboard and mouse, which was an adherence rate of only 9.3%.[127] In their study, over one-third of the keyboards tested positive for MRSA. A high percentage of bacteria-contaminated keyboards indicates both poor hand hygiene among healthcare staff and poor cleaning of the keyboards. The chairs in the patient changing room and the pillows on the head support were also surfaces with a high number of CFU in both public and private CT examination rooms. These are also areas that come in close contact with the skin of the patient, similar to the case in the study with X-ray cassettes.[62] The skin microbiome consists mostly of Gram-positive bacteria,[128,129] including at least transiently *S. aureus*. In our study, the Gram-positive bacteria dominated, which is consistent with the fact that we measured surfaces that often come into contact with the skin in some way. In a study conducted on bacterial contamination of CT equipment, they measured bacterial contamination of the CT bore, CT table and CT wrap.[130] It was found that the CT wrap was the most contaminated surface, then the table and then the bore. This also shows that materials that are most often in close contact with the skin are usually the most contaminated. In our study we did not measure the CT wrap and the CT bore, but we showed that CFU were above the limit on the sides of the CT table. In the MRI examination rooms in both public and private radiology departments, the headphones and the alarm control/buzzer had considerably more CFU than the limit of 2.5 CFU/cm^2. This equipment is, of course, in close contact with the patient's skin. We also measured extreme values, primarily on the headphones (169 CFU/cm^2 in a private radiology department and 50.8 CFU/cm^2 in a public radiology department), which could have been removed and treated as outliers. However, we chose to retain and report these values because, we think these are true results and reflect the reality that sometimes some surfaces are poorly cleaned.

The medicine trolley was the least contaminated surface in both the public and private radiology departments' CT- and MRI examination rooms. These are mostly where the contrast media and medication are prepared, and the surface is not exposed to lot of hand contact. Perhaps it is a surface that most staff also clean. There are not many previous studies regarding bacterial contamination of medicine trolleys. In a previous study performed in a radiology department, various surfaces were investigated for MRSA, including the medicine trolley, which was MRSA negative.[68] Another surface inside the MRI examination rooms in both public and private radiology departments where near zero CFU were measured was the sides of the MRI tunnel/bore. This is interesting because most patients come in contact with the surface when they enter the MRI tunnel/bore. Perhaps it is because the staff are careful to disinfect that surface, or perhaps it is due to closeness to the magnetic field. In other studies where only the magnetic field's influence on bacteria has been studied, the growth curves of different bacteria decreased with increasing magnetic field intensity and increasing time of exposure.[131,132] In another study, *E. coli*, *Leclercia adecarboxylata* and *S. aureus* were studied, in terms of how they were influenced by different magnetic fields and exposure times.[133] That study also showed that increased field strength and exposure time reduce bacterial growth. *E. coli* was the most sensitive and *S. aureus* the least sensitive of the three tested bacteria. Thus, it is possible that, it is the sensitivity of bacteria to magnetic fields that reflects a part of the outcome of our study. The magnetic field's influence of bacteria at a cellular level has also been studied in order to explain the reduction of the growth curve.[133,134] There, among other things, it has been seen that the cell diameters have decreased and the surface of cells has changed. Thus, one might ask the question of how the human cell is affected in the magnetic field, but this is beyond the scope of our research and is more a reflection.

5.3 DIFFERENCES IN BACTERIAL CONTAMINATION OF SURFACES IN THE CT AND MRI EXAMINATION ROOMS BETWEEN PUBLIC AND PRIVATE RADIOLOGY DEPARTMENTS

We could not find any significant difference between public and private radiology departments regarding the number of CFU on hand-touched surfaces inside the CT- and MRI examination rooms. The fact that we included the aspect of differences between public and private healthcare in the purpose of the study was based on the statement that the conditions can differ between these two. In our study conducted in Swedish radiological departments, the participating private radiology departments mostly have outpatients who can mostly take care of themselves and are mobile, while the public radiology departments mostly have inpatients who often are more seriously ill. Another difference is that production is usually higher in private radiology departments with shorter time per patient, which could have resulted in the staff not being able to clean the study rooms equally well between each patient. On the other hand, patients in public healthcare are often more infected or may come from major accidents with open wounds.

There are not many previous studies where differences between public and private healthcare have been studied from a hygiene perspective. The studies that have led to different conclusions. In a German study of intensive care units, they looked at differences between altered ownership conditions of hospitals in terms of urinary catheter-associated urinary tract infections, surgical site infections following hip prosthesis, central venous catheter associated bloodstream infections, endpoints ventilator-associated pneumonia, colon surgery, MRSA, *Clostridoides difficile* infections and hand rub consumption per 1,000 patient days.[135] They could not find any major differences between different hospitals regarding the ownership structure. In another study, bacterial samples were taken from different pieces of X-ray equipment, for example, X-ray cassettes and exposure buttons and showed that the prevalence of bacteria isolated from public institutions was higher than from private institutions.[59] In an Australian study, a similar result was obtained, but in that study they looked at nosocomial and community-acquired infections in different hospitals in Australia.[136] They also concluded that nosocomial and community-acquired infections were more common in public hospitals (nosocomial infections = 6.7% and community-acquired infections = 10.6%) compared to private hospitals (nosocomial infections = 4.8% and community-acquired infections = 6.3%). They also found that community-acquired infections were more common in rural than in metropolitan hospitals. The differences between public and private care regarding HAIs, bacterial contamination of surfaces, and adherence with hygiene guidelines might be due to other things than the form of ownership of the hospital or clinic. The attitude and commitment of hygiene-related issues in management, whether in public or private care, seem to be of major importance for infection prevention.[137,138] Good leadership usually propagates through the entire organisation, which in this case favours infection prevention when the staff feel motivated and involved.[139] There is potential for much more research in this area, especially looking at what leads some healthcare providers to have better hygienic standard than others.

5.4 ADHERENCE WITH HYGIENE GUIDELINES

Our study shows that most of the staff assess their knowledge of hygiene guidelines as high and feel that they have the necessary knowledge needed to work safely with the patients. They did not consider that they needed more education in the field of hygiene. Most of the managers felt that the hygiene guidelines were followed to some extent. However, they had noted that the guidelines on hand hygiene were not followed to the same extent as the staff felt they were, for example, gloves were overused. It is not uncommon that the perception of one's own knowledge of how to act in practice does not always correspond to reality.[140] In a combined observation and survey study about hand hygiene behaviour among 57 healthcare professionals, 87.9% reported adherence to hand hygiene, while the observed adherence rate was only 19 % ($p<0.001$).[141] This phenomenon was also demonstrated in another cross-sectional study, where the actual behaviour among the participants was not in line with the self-reported behaviour.[142]

Not following guidelines on hand hygiene is not uncommon and there might be many reasons for this. This could be due to lack of knowledge, but in Sweden hygiene is included in most undergraduate programmes for hospital staff at the university, so lack of knowledge does not seem to be the most likely cause here. It is also apparent in our study that both staff and managers consider themselves well-acquainted with hygiene guidelines. But one must of course consider that everyone has not been educated in Sweden. Studies have also shown that education does not need to mean better adherence with hygiene guidelines.[143] Jenner et al.[142] mention in their article that there is no similarity between education and behaviour. In order to understand and explain why guidelines are not followed, knowledge has been taken from behavioural science. The theory of planned behaviour (TBP) has been used in some studies to explain the behaviour of hand hygiene.[144] The TPB is based on the direct cause of a planned behaviour for example the intension to perform hand hygiene. The intention can then be divided into three variables, namely attitude (a person's feelings for the behaviour), subjective norm (a person's sense of social pressure), and perceived behavioural control (how easy or difficult the person thinks something is to perform). O´Boyle, Henly and Larson[140] could not relate healthcare personnel adherence with hand hygiene to TPB, but rather related adherence with hand hygiene to the workload. In our study we also concluded that stress and lack of time were reasons for not following hygiene guidelines.

Hand hygiene and use of gloves emerged in our study when managers were asked what they thought staff did not do according to the hygiene guidelines, and these have been seen in other studies.[145-147] Some wear gloves primarily to protect themselves[148] and this was evident in a semi-structured interview study conducted in England where one of the quotes was "*I am more cautious about myself than whether I am passing on [.] infection from one patient to the next patient. I'll be honest.*"[148](page 113). To counteract the overuse of gloves, staff need to feel secure in following basic hygiene practices. It is probably not more education about basic hygiene guidelines that is required, but rather education about pathways of infection and increased knowledge about the different life cycles of microorganisms. The managers also mentioned in our study that it is important that there is a good organisation in the department that promotes good hygiene practices. Other studies have also shown that the culture and organisation of a department are important for how closely guidelines are followed.[149,150]

5.5 METHODOLOGICAL CONSIDERATIONS

5.5.1 Study I

This study had some limitations. In order to increase the reliability of the study, it would have been an advantage if we could have taken more than one sample than one sample from each surface and even on different occasions, which has been done in some other studies.[151,152] We used a traditional method of measuring bacteria on a surface by colony-count analysis, but an alternative could have been to use an ATP- based detection system. The ATP-based method is cheaper and faster[153] than the colony-count method, which could have allowed repeated sampling as well as increased numbers of test areas. There is a limitation with the ATP-based method, in that gram-negative bacteria are difficult to detect;[154] however, the gram-positive bacteria predominated in our study. Also, to better reflect reality we should have taken the samples without the staff knowing it, and a possible bias in this study is that the staff knew that bacterial samples would be taken and thus might have been more careful with cleaning. Finally, to get a more equally distributed material it would have been favourable to have as many private clinics as public clinics participating. Despite these limitations, we still believe that our study provides a guide to those surfaces that are often forgotten to be cleaned inside and outside the CT and MRI examination rooms.

5.5.2 Study II

A limitation of this study was that some respondents skipped answering some questions, which for some questions gave a low response rate that, might affect the reliability of the results for that individual question. The open questions were answered by both the staff and the managers with usually just one word, which limited the amount of data and made it difficult to use regular content analysis methods. In order to increase the validity of the study a method of triangulation could have been carried out with a supplementary interview study.

Another weakness of the study was that we wanted to get a wider spread regarding the professional affiliation of the staff who completed the survey and who worked with CT and MRI. The questionnaires were distributed to radiologists, radiographers and assistant nurses. Only two radiologists and ten assistant nurses answered the questionnaire and the rest were radiographers, so we decided not to make any comparisons between the various occupational categories but treated everyone as a group. Some radiology departments also did not have any assistant nurses and many radiologists can work from home. Despite the study's shortcomings, there are still clear factors that affect the staff's adherence with hygiene guidelines, which we hope can be useful in the continued work to prevent HAIs.

6 CONCLUSIONS

In summary, staff working with CT and MRI generally have good hygiene training, both in public and private radiology departments. They have managers who prioritise education and hygiene issues in their radiology departments, which provides a good basis for a reliable hygienic standard to prevent HAIs. The assessment of bacterial contamination of surfaces did not reveal any MDR indicator microorganisms, but a number of surfaces had a bacterial contamination that exceeded the limit of 2.5 CFU/cm^2. Exposed surfaces for bacterial contamination included chairs in the patient changing room, keyboards, the sides of the examination table, the support pillows, the headphones and the alarm control/buzzer. The main factors that influence staff not to follow the hygiene guidelines are primarily that they feel stressed and that there is not enough time to follow the guidelines completely. Even in emergency situations, personnel ignore the guidelines. The managers also state that they believe that stress and lack of time are a major reason why the staff do not follow the guidelines. The hygiene guidelines that according to the managers are most lacking among the staff are hand hygiene and cleaning the equipment between patients.

7 FUTURE RESEARCH

There are still many areas to explore regarding infection control and the spread of infection. One of the places where the number of bacteria was very low was inside the MRI tunnel. Some other studies have shown similar results, but further research would be needed on how the magnetic field inside the MRI tunnel affects the growth of different bacteria. Further studies on how bacteria grow on different materials used in, for example, support pillows would also be of importance, because support pillows were found among those surfaces with high CFU/cm^2. It could also be of interest to perform an observational study on how the staff of public and private radiology departments' CT and MRI staff follow the basic hygiene guidelines and to compare this with how the staff estimated that they follow hygiene guidelines in the completed survey study.

8 ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to my surroundings from castle to hut with a special thanks to the people who helped me reach the goal of a licentiate thesis:

Professor Christian G. Giske, my head supervisor who jumped into the study and took over after my previous supervisor retired. Without you, I would never have finished my licentiate degree.

Professor Gunnar Sandström, my former supervisor. You showed me the door to the science world.

MD, PhD Anders Samuelsson, my co-supervisor. You have always made valuable comments that moved the work forward.

PhD Kent Fridell, my Division Head and co-supervisor who enabled this work.

Docent Ann-Christin Johnson, my mentor who encouraged me along the way.

PhD Parvin Tavakol, my mentor and friend thanks for all the fruitful chats.

MD, PhD Inga Fröding, who took the time to give me both practical and theoretical advice on my way to the licentiate degree.

Agneta Wittlock, for your assistance, it has meant a lot.

Anna Springfeldt-Ejebro, for all your help in the laboratory.

Jessica Ekberg, for all help with administration.

All my **current and former colleagues** at the division of radiography: *Annica Sandberg, Hanna Dumky, Linda Wennberg, Anna Ek-Jörneklint, Tiina Hellebring, Parvin Tavakol Olofsson, Karin Green* and the *staff* at Odenplan's radiology department, thanks for all the rewarding conversations.

Thanks to my **friends** at the division of Audiology: Åsa Skjönsberg, Heléne Bergström, Annica Hagerman-Sirelius, Jeannette Hägerström, Marlin Johansson, Katrin Vonderschen, Satu Turunen-Taheri, Monica Beckius-Hellgren, for stimulating conversations at lunch.

Finally, my **family**, **friends** and **pets**, it's been wonderful to have you as a fantastic support team on my way to my degree.

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