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Surface Contamination of CT and MRI Equipment—A Potential Source for Transmission of Hospital-Acquired Infections

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A B S T R A C T

Hospital-acquired infections (HAIs) are a major problem for health care worldwide. These infections cause additional suffering for the patient and infer major societal costs. There has been extensive research on infection transmission in health care, but to a lesser extent within the field of radiology. The purpose of this study was to identify selected hand-touched surfaces inside and outside the computed tomography (CT) and magnetic resonance imaging (MRI) examination rooms which are prone to contamination and which could represent a risk for transmission of HAI pathogens. We also aimed to examine differences in bacterial contamination between public and private radiology departments. Six public and four private radiology departments participated in the study. Bacterial samples were taken from ten predetermined 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, bacterial colony-forming units (CFU) per cm^2 were calculated. Bacterial CFU were found on almost all selected surfaces. The highest numbers were found on keyboards, chairs of the patient changing rooms, headphones, and the alarm control/buzzer. There was no significant difference between public and private radiology departments. No multidrug-resistant microorganisms such as methicillin-resistant *Staphylococcus aureus*, extended-spectrum beta-lactamase–producing *Enterobacterales*, or carbapenemase-producing *Enterobacterales* were found in any of the investigated radiology departments. Both the CT and MRI equipment in public and private radiology departments may be potential sources of pathogenic bacteria, and disinfection between patients should be improved.

Introduction

Hospital-acquired infections (HAIs) are a major concern worldwide (Khan et al., 2017; Suetens et al., 2018). HAIs are infections that occur in the context of hospital care, when the patient is either hospitalized or attending health care appointments for diagnostics or treatment. HAIs cause patients significant suffering and are expensive for society. In high-income countries, around 7% and in low-income countries, around 10% acquire an HAI (Khan et al., 2017). The costs for HAIs in the United States is estimated to be $35.7-45 billion (Storr et al., 2017). In Europe, HAIs generate 16 million extra care days at a cost of EUR 7 billion per year (World Health Organization, 2011). In Sweden, HAIs cause 750,000 extra care days each year at a cost of EUR 670 million (Sveriges Kommuner och Landsting, 2014). From a point prevalence study conducted in Sweden covering the time period from 2008 to 2013, it was observed that 8.3% of hospitalized patients had an HAI (Tammelin & Qvarfordt, 2015).

The increase of antimicrobial resistance makes many HAIs more complicated to treat, as they are frequently caused by resistant pathogens (Mancini et al., 2016). Common antibiotic-resistant bacteria in the health care setting include Gram-positive

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cocci—mainly methicillin-resistant *Staphylococcus aureus* (MRSA) (Haaber et al., 2017) and vancomycin-resistant *Enterococci* (VRE) (Faron et al., 2016), and Gram-negative bacilli—mainly *Escherichia coli* and *Klebsiella pneumoniae* producing extended-spectrum beta-lactamases (ESBL) and carbapenemases, conferring resistance to cephalosporins and carbapenems (Kaye & Pogue, 2015). Globally, there are large differences in the presence of MRSA (Hassoun et al., 2017). The prevalence of resistant isolates of MRSA increases from north to south in Europe. In 2014, it ranged from 0.9% in the Netherlands to 56% in Romania. In Sweden, the prevalence of MRSA is still low, about 1% of *S. aureus* isolates from blood cultures (Dahlman et al., 2017).

For investigation of the standard of surface-level cleanliness in health care, international standards from the food industry have been applied (Dancer, 2004). From a sampled area, the total number of aerobic organisms can be measured as aerobic colony counts (ACCs), expressed as colony-forming units (CFU)/cm^2. The surfaces in the food industry and in health care are not completely comparable; therefore, hand-touched areas that can represent a transmission risk for the patient have been used as a reference surface when measuring ACCs in health care. The stated limit of ACCs on hand-touched surfaces was previously <5 CFU/cm^2 but has been reduced to <2.5 CFU/cm^2 (Harvin et al., 2016; Saleh et al., 2018). Microorganisms of high infection control concern (due to their propensity of conferring HAIs) such as MRSA can be used as indicator organisms when measuring surface contamination (Dancer, 2004). For microorganisms of high infection control concern, the limit is <1 CFU/cm^2.

Standards of hygiene in health care have been studied extensively (Khan et al., 2017). One example is whether inanimate surfaces can contribute to the transmission of HAIs (Suleyman et al., 2018). In a review article, the conclusion was drawn from previous epidemiological studies, microbiological studies, outbreak reports, and intervention studies that surfaces can be a potential source of hospital pathogen transmission (Otter et al., 2013). The question of whether inanimate objects in the radiology department can cause cross-contamination among patients has been studied to some extent. In one study of lead aprons, bacterial samples were taken before and after cleaning from different areas on the apron (Boyle & Strudwick, 2010). There was a significant difference after cleaning in the reduction of CFU. A similar study was carried out on protective lead garments (thyroid shields, shoulder-vests, and wrap-around skirts) in surgical operating units (La Fauci et al., 2016). Of 109 sampled garments, 88 had bacterial contamination. Hygiene studies have also been carried out on radiographic markers (Hodges, 2001; Tugwell & Maddison, 2011) and on X-ray cassettes (Fox & Harvey, 2008; Lawson et al., 2002), which often come into contact with the radiographer's hands and the patient. In summary, the markers and the X-ray cassettes can be a reservoir for bacterial dissemination and in one study, MRSA was found on six of 37 examined X-ray cassettes (Kim et al., 2012). In an earlier study involving bacteriological diagnostics (Childress et al., 2017), samples were taken from computed tomography (CT) equipment (CT bore, CT table, and CT wrap), and the results revealed that the CT wrap was the equipment most contaminated with bacteria, which led to a new cleaning process.

The number of radiology examinations has increased over the years, in particular, the more technically advanced imaging modalities, such as CT and magnetic resonance imaging (MRI) (Fatahi & Speck, 2015; McCollough et al., 2015). A variety of patients pass through the radiology department, patients prone to infections, asymptomatic carriers, and patients with clinical infections. This places high demands on the cleaning of the machines between patients and requires that guidelines for hygiene procedures are followed. There could also be potential differences in hygiene between public and private hospitals. In a study concerning hand hygiene in public and private hospitals, it was concluded that hand hygiene was better in private hospitals than in public hospitals (Ye et al., 2017).

The purpose of this study was to identify selected hand-touched surfaces inside and outside the CT and MRI examination rooms which are prone to contamination and which could represent a risk for transmission of HAI pathogens. Furthermore, the aim was to study whether MRSA, *E. coli*, or *K. pneumoniae* with ESBL or carbapenemases could be detected in CT and MRI examination rooms. Finally, we also aimed to determine whether there were any differences in bacterial contamination between public and private radiology departments.

Materials and methods

The managers of six public radiology departments and six private radiology departments in Stockholm, the capital of Sweden, were contacted to participate in the study. All except two of the private radiology departments agreed to participate. Both public and private X-ray departments were included, as it may differ between them with respect to patient flow that is usually higher in the private X-ray departments because of a majority of outpatients. The public X-ray departments have both outpatients and inpatients. All the radiology departments mainly examined adult patients. Bacterial samples were collected between 1st Oct and 31st Dec 2016. The study was approved by the Regional Ethics Committee in Stockholm (recordal 2015/2288-31).

A chart for bacterial sampling of surfaces inside and outside the CT and MRI examination rooms was prepared based on frequently hand-touched areas and areas measured in an earlier study of Shelly et al. (2011) (Table 1). The sampling surfaces, the size of the areas to be swabbed, as well as the indicator organisms MRSA and ESBL-producing *Enterobacterales* (EPE) and carbapenemase-producing *Enterobacterales* (CPE) were determined by discussion in the study team, which comprised expertise in radiology, infection control, and microbiology, with support based on previous studies (Dancer, 2004; Shelly et al., 2011). To best reflect hygienic levels in normal workflow, samples were taken in the middle of the day between patients. The radiology staff were informed about the study and had been instructed to clean the equipment according to hygiene guidelines. The hygiene guidelines are the same in the whole country, and the X-ray departments basically have the same cleaning routines. Regardless of the workplace, the staff are trained to comply with the national hygiene guidelines. The same person took all samples on all occasions. Before sampling, hands were disinfected with alcohol-based hand disinfection. Sampling was carried out with flocked nylon swabs (Copan Liquid Amies Elution Swab [Eswab] Copan, Brescia, Italy) (Dalmaso et al., 2008; Hedin et al., 2010). The flocked nylon swabs were presoaked in the Liquid Amies medium before sampling and then a 100 cm^2 surface was swabbed in a rotating zig-zag pattern (Griffith et al., 2007). A 100 cm^2 template was used to mark the sample area on surfaces. The inside of one headphone and the whole alarm control/buzzer in the MRI examination room were swabbed separately. After sampling, the swab was placed in the Liquid Amies medium for transport to the Karolinska University Laboratory, Department of clinical microbiology, and subsequent culture. The tubes were vortexed for 1 minute, and from each sample, 100 μL was spread on five different agar plates, one blood agar plate, one chocolate agar plate, and selective agars for EPE, CPE, and MRSA.

All plates were incubated at 37°C in 5% carbon dioxide (chocolate agar), or air for 48 hours. The total number of CFU on the agar plates was calculated from each sampling surface as a measure of bacterial contamination (Tugwell & Maddison, 2011). For species

Table 1
Sampled areas inside and outside 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)
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 on the 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

CT = computed tomography; MRI = magnetic resonance imaging.

identification of Gram-negative bacteria, matrix-assisted laser desorption ionization time of flight (MALDI-TOF) (Bruker, Bremen, Germany) was used.

The results were presented as a measured number of ACCs as CFU/cm^2, which is the convention for reporting surface contamination. In this study, <2.5 CFU/cm^2 was used as a limit (Claro et al., 2015). The data were entered into Microsoft Excel. A two-tailed t-test was used to calculate p-values. To calculate the ellipse-shaped surface area of the headphone and the alarm control, the approximate Thomsen's formula was used. IBM Statistical Package for Social Sciences (SPSS) statistics 25 was used for the diagrams.

Results

Detection of Bacteria on Inanimate Surfaces

Gram-positive bacteria dominated in the bacterial microbiota both inside and outside the CT and MRI examination rooms, whether it was public or private radiology departments. Only three Gram-negative species were identified in total. None of the indicator organisms, such as MRSA, EPE, or CPE, were found in any of the investigated radiology departments. The result showed that 3/10 measured surfaces in the public CT laboratories had a median value >2.5 CFU/cm^2, the corresponding number for private CT laboratories were 6/10 (Figure 1). For the MRI laboratories, public MRI had 6/10 surfaces with >2.5 CFU/cm^2, and the corresponding number for private MRI laboratories was 8/10 (Figure 2). The most contaminated surfaces inside and outside the CT examination rooms were basically the same in both the public and the private radiology departments; side of the examination table, keyboards, chairs in the patient changing room, and pillows in the head supports (Figure 1). The highest measured value of CFU/cm^2 was 20 on the side of the examination table, 11 on the keyboard, 10 on the chairs in the patient changing room, and 10 on the pillows in head supports. High values of CFU/cm^2 were also measured in the public CT radiology departments on the control panels on the contrast injector 10 CFU/cm^2. In the private radiology department, high values of CFU/cm^2 were also measured on the center of the examination table—10 CFU/cm^2—and the support pillow—8 CFU/cm^2 (Figure 1). 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 (Figure 1). A low number of CFU was also found on the center of the examination table in the public radiology department's CT rooms; one of six rooms' cultures were negative (0 CFU/cm^2) (Figure 1). There was a significant difference in both public and private radiology departments, between

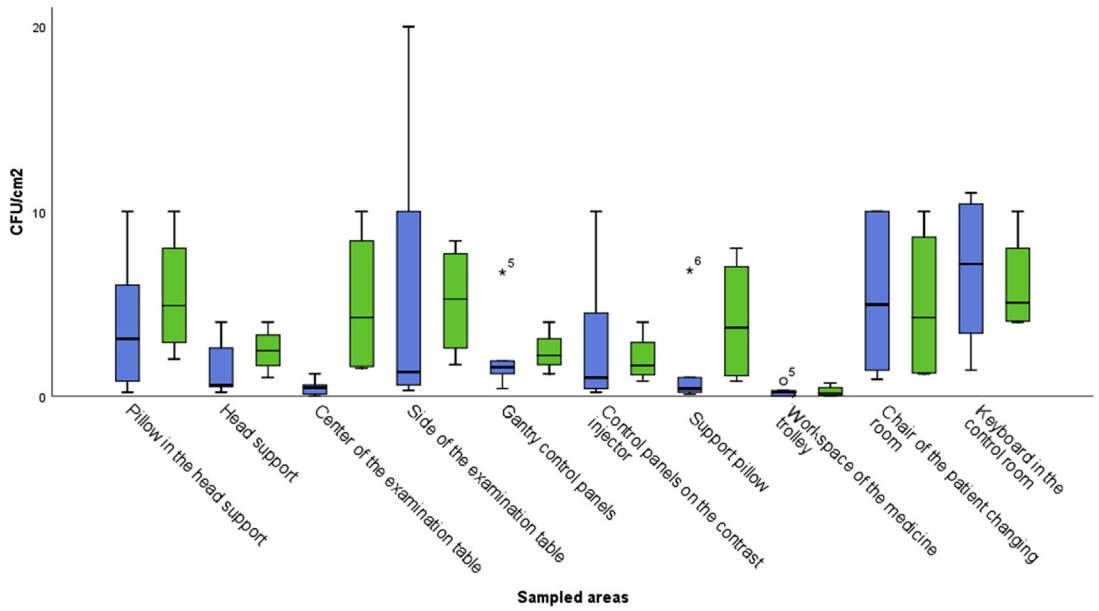

Figure 1. Number of CFU/cm^2 of Gram-positive bacteria on different hand-touched surfaces inside and outside the CT examination room of public and private radiology departments. Blue = public CT departments, green = private CT departments. CFU = colony-forming units; CT = computed tomography. In the diagram the rings are outliers where the values do not fall within the limits. The asterisks are extreme outliers, which means their value lie more than three times the height of the boxes. The numbers are case numbers. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

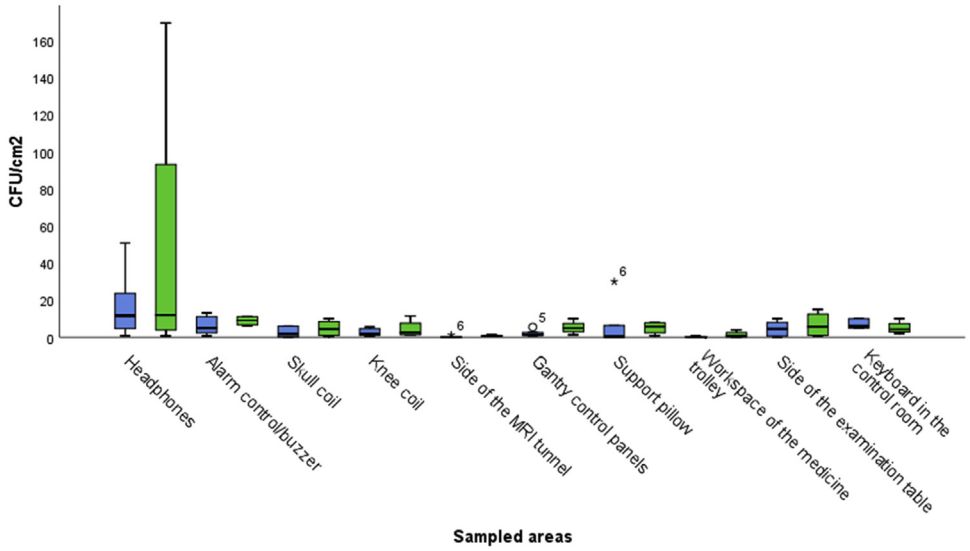

Figure 2. Number of CFU/cm^2 of Gram-positive bacteria on different hand-touched surfaces inside and outside the MRI examination room of public and private radiology departments. Blue = public MRI departments, green = private MRI departments. MRI = magnetic resonance imaging. In the diagram the rings are outliers where the values do not fall within the limits. The asterisks are extreme outliers, which means their value lie more than three times the height of the boxes. The numbers are case numbers. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

the CFU count on the medicine trolley and the keyboard in the control room ($p = .01$ and $p = .02$, respectively).

In the MRI examination rooms in both the public and private radiology departments, the headphones, support pillow, and the alarm control/buzzer were among the most contaminated areas (Figure 2). The highest measured value of CFU/cm^2 was 169 on the headphones and the support pillow 30 (Figure 2). For the alarm control/buzzer, the highest number of CFU/cm^2 was 13 (Figure 2). The keyboard, the side of the examination table, and the gantry control panels were also areas where the median values were more than 2.5 CFU/cm^2 (Figure 2). In the MRI examination room in both the public and private MRI radiology departments, the least contaminated surfaces were the medicine trolley, with a range between 0.1 and 4 CFU/cm^2, and the side of the MRI tunnel, with a range between 0 and 1.4 CFU/cm^2 (Figure 2). In both the public and the private MRI departments, there was a significant difference in CFU counts between the least contaminated workspace on the medicine trolley and the alarm control/buzzer ($p = .03$ and $p = .005$, respectively).

Differences in the Number of CFU/cm^2 for Public and Private CT and MRI

The median colony count for all the ten measured areas in each public and private radiology department, with respect to surfaces inside and outside the CT and MRI examination rooms, are shown in Figures 3 and 4. One of six public radiology departments' CT examination areas (Figure 3) had a median colony count (3.4) that

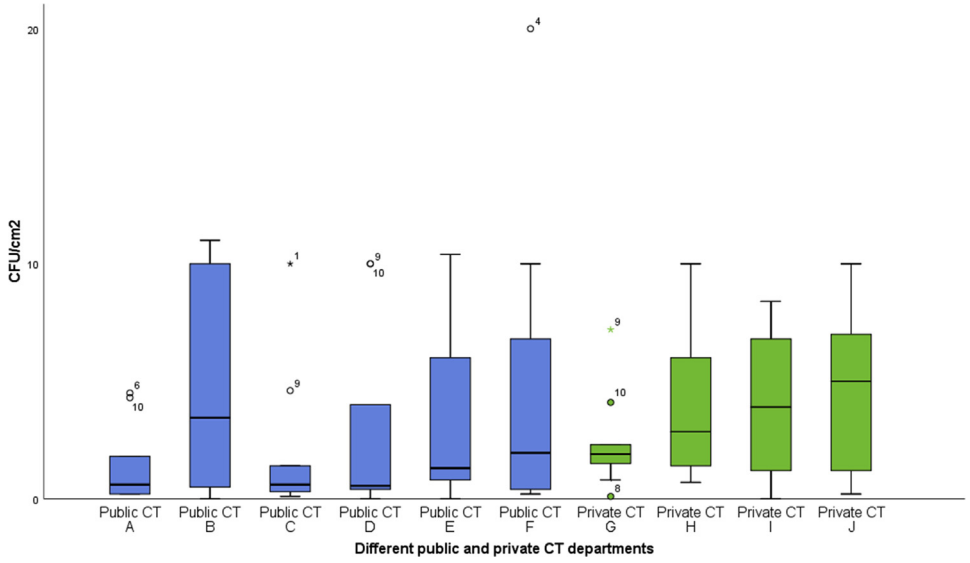

Figure 3. One of six public radiology departments' CT examination areas had a median colony count (3.4) higher than 2.5 CFU/cm^2 limit. Three of four private radiology departments' CT examination areas had a median colony count higher than 2.5 CFU/cm^2 limit, ranging between 2.8 and 5 CFU/cm^2. Blue = public CT departments, green = private CT departments. CFU = colony-forming units; CT = computed tomography. In the diagram the rings are outliers where the values do not fall within the limits. The asterisks are extreme outliers, which means their value lie more than three times the height of the boxes. The numbers are case numbers and the letters represents different CT departments. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

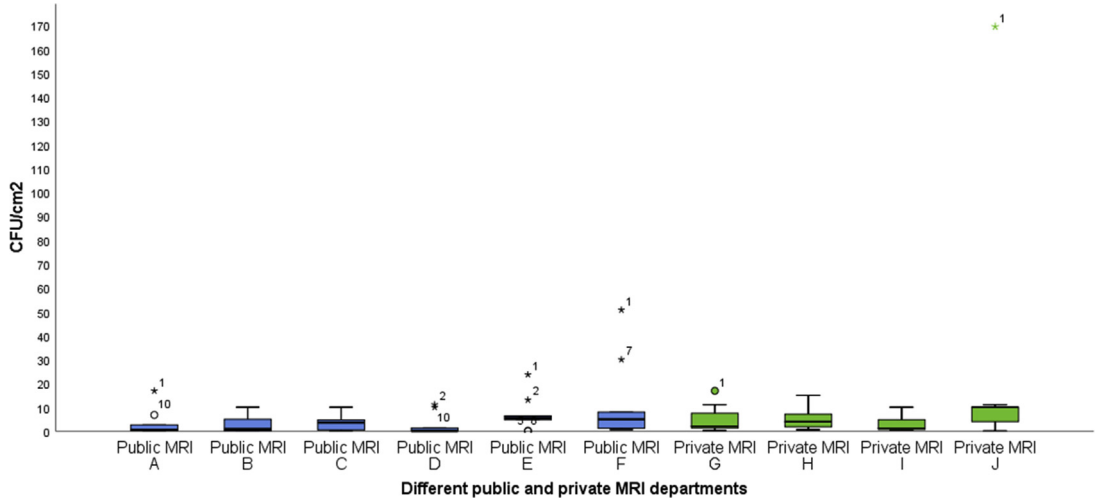

Figure 4. Three of six public radiology departments' MRI examination areas had a median colony count higher than 2.5 CFU/cm^2 limit, ranging between 3.1 and 5.2. Two of four private radiology departments' MRI examination areas had a median value higher than 2.5 CFU/cm^2 limit, ranging between 5.1 and 8.5. Blue = public MRI departments, green color = private MRI departments. CFU = colony-forming units; MRI = magnetic resonance imaging. In the diagram the rings are outliers where the values do not fall within the limits. The asterisks are extreme outliers, which means their value lie more than three times the height of the boxes. The numbers are case numbers and the letters represents different MRI departments. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

exceeded the 2.5 CFU/cm^2 limit. The lowest median colony count was 0.6, observed in two of the public radiology departments' CT examination areas (Figure 3). Among the private radiology departments' CT examination areas, a median colony count that exceeded 2.5 CFU/cm^2 limit was seen in three of four radiology departments, having median colony counts ranging between 2.8 and 5 (Figure 3).

Among the public radiology departments' MRI examination areas, three of six had a median colony count exceeding the 2.5 CFU/cm^2 limit, ranging between 3.1 and 5.2 (Figure 4). Of the four private radiology departments' MRI examination areas, two had a median colony count exceeding the 2.5 CFU/cm^2 limit, ranging between 5.1 and 8.5 (Figure 4).

No statistically significant difference was found between public and private radiology departments in the number of CFU/cm^2.

Discussion

Gram-positive bacteria were much more abundant than Gram-negative bacteria in the radiology department setting. Similar rates of Gram-positive and Gram-negative bacteria have been seen in other studies (Tajeddin et al., 2016). Potential reasons could be that Gram-positive bacteria have been shown to have a greater survival capacity in the inanimate environment (Lemmen et al., 2004), and that Gram-positive bacteria also form a large part of the skin microbiota (Chiller et al., 2001). No bacteria of high infection control concern were identified from the sampled surfaces. The prevalence of MRSA is very low in Sweden (Childress et al., 2017), and the likelihood of finding MRSA on inanimate surfaces is therefore expected to be low. Earlier studies conducted in radiology departments in the United Kingdom regarding cassettes and lead aprons found no MRSA (Boyle & Strudwick, 2010; Fox & Harvey, 2008). There are, however, other studies that have identified MRSA. In a study conducted in Ireland, 125 samples were taken from clinical and nonclinical areas in a radiology department after disinfection. One sample from the surface of the bore in the MRI camera was positive for MRSA (Shelly et al., 2011). Wood and Britt (Wood & Britt, 2010) were able to demonstrate MRSA on an X-ray cassette used in the operating room. In general, the sample area constitutes only a small part of the total surface, which may hamper the sensitivity for detection of resistant bacteria in low abundance.

Furthermore, the present study aimed to identify any surfaces inside and outside the MRI and CT examination rooms, which were more prone to bacterial contamination than others. The keyboards had a high amount of CFU/cm^2 in most CT and MRI control rooms, in both public and private radiology departments. This has also been demonstrated in other studies (Al-Ghamdi et al., 2011; Duszak et al., 2014; Harvin et al., 2016; Rutala et al., 2006). A possible reason for this could be that health care workers do not disinfect their hands properly after working with the patient inside the examination room or by not disinfecting the keyboards regularly. The importance of hand hygiene when it comes to disease transmission has been extensively studied (Forrester et al., 2010). Thoroughness with hand hygiene is the easiest, most efficient, and cheapest way to stop cross-contamination with microorganisms.

The chairs in the patient changing rooms also showed a high number of CFU/cm^2 in most of the cases. One reason could be that patients take off their clothes in these rooms, and many patients are sitting on the chairs in their underwear. Furthermore, the side of the examination table had a high number of CFU/cm^2. This might be because patients' skin comes in close contact with the side of the examination table as they step on and off the examination table. Likely, the chairs in the patient changing rooms and the side of the examination table are not disinfected sufficiently.

In general, many surfaces had bacterial values that exceeded the limit of 2.5 CFU/cm^2, which means that the surface is not sufficiently cleaned and can be a source of infection transmission. This could, for example, be due to insufficient staff education on infection control or that the method of cleaning is not optimal. There is much to consider when choosing a cleaning method. It should be effective, but not adversely affect the human being or the environment, as well as be cost-effective (Dancer, 2016). Altered cleaning methods also affect different pathogens differently. Hydrogen peroxide cleaning is effective against bacteria and viruses but toxic to humans and cannot be used in continuous cleaning (Dancer, 2016; Rock et al., 2018). Ultraviolet C light has also been shown to be effective in killing pathogens (Dancer, 2016; Kovach et al., 2017), but it can contribute to a faster aging of plastic materials. There has also been studies about self-disinfecting surfaces covered with copper and silver, which has been shown to reduce HAI (Boyce, 2016). More studies are needed on how different disinfection methods can be combined to achieve the best effect

with regard to the pathogen, the efficiency, the environment, and the economy.

Surprisingly, a low number of CFU/cm^2 was found on the side of the tunnel in the MRI camera in both public and private radiology departments. This area is probably not disinfected more frequently than other areas of the machine, and patients touch it nearly every time they enter the machine. Interestingly, prior studies have shown that the growth curve decreases for bacteria in a magnetic field (Fojt et al., 2004; Salmen & Alharbi, 2017; Strašák et al., 2002). The growth rate of *E. coli* decreases with increasing exposure time and stronger magnetic fields (Strašák et al., 2002). However, a difference has been noted between bacterial species, whereby *E. coli* apparently is more sensitive than *S. aureus* (Fojt et al., 2004). However, other surfaces in the MRI examination room did not appear to be affected. Further studies should be carried out with respect to the impact of magnetic fields on bacterial counts.

We were unable to find any significant differences between public and private radiology departments regarding bacterial contamination. A German study about hospital ownership and the presence of HAIs was carried out in intensive care units and surgery departments specializing in hip prosthesis and colon surgery and was unable to demonstrate any definitive difference in HAIs based on hospital ownership (Schroder et al., 2018). Further studies are needed to learn about differences between public and private health care.

One limitation of this and similar studies is the lack of a standardized method for bacterial sampling. It is difficult to take samples with 100% consistency over time, as the surfaces and machines have different designs. We have tried to mimic the methods used in similar previous studies and other hygiene studies (Giacometti et al., 2014; Fox & Harvey, 2008). We used the flocked nylon swabs, as in other studies, to best capture low levels of bacteria and MRSA from the selected surface (Dolan et al., 2011; Hedin et al., 2010). The staff's awareness that levels of bacteria would be measured may have affected the results, that is, causing a tendency toward better hygienic routines.

Another limitation is that the study was only performed during the daytime, and it cannot be excluded that the results could have been different if sampling was also carried out during on-call hours.

Conclusion

No multidrug-resistant indicator microorganisms were found in the study, but a number of surfaces had bacterial concentrations that exceeded the limit of 2.5 CFU/cm^2. Hence, the disinfection of surfaces between patients should be improved especially with regard to chairs in patient changing room, keyboards, the side of the examination table, headphones, and alarm control/buzzer. There was no significant difference between public and private radiology departments. Further studies on how the magnetic field affects bacterial growth, together with how different materials affect the survival of the bacteria, would be of interest. It would be of interest to make a larger study and look at differences between radiology departments that work with children, inpatients, and outpatients regarding hygiene routines and the staff's attitude to hygiene issues.

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