Journal of Hospital Infection 112 (2021) 31–36

Available online at www.sciencedirect.com

Journal of Hospital Infection

journal homepage: www.elsevier.com/locate/jhin

How dirty is your QWERTY? The risk of healthcare pathogen transmission from computer keyboards

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ARTICLE INFO

Article history:
Received 3 February 2021
Accepted 21 February 2021
Available online 26 February 2021

Keywords:
Keyboard
Health care
Contamination
Transferability
Dry surface biofilm

SUMMARY

Introduction: Healthcare environmental surfaces may be contaminated with micro-organisms that cause healthcare-associated infections (HCAIs). Special attention is paid to near-patient surfaces but sites outside the patient zone receive less attention. This paper presents data on keyboard contamination and the risk of pathogen transmission from keyboards.

Methods: Keyboards from nursing stations in three hospitals and a dental practice were analysed for bacterial contamination. Surfaces were pre-treated to remove planktonic bacteria so that any remaining bacteria were presumed to be associated with biofilm. Bacterial transfer from keyboard keys was studied following wiping with sterile water or sodium hypochlorite. The presence of multi-drug-resistant organisms (MDROs) was sought using selective culture.

Results: Moist swabbing did not detect bacteria from any keyboard samples. Use of enrichment broth, however, demonstrated MDROs from most samples. Gram-negative bacteria were recovered from almost half (45%) of the samples, with meticillin-resistant *Staphylococcus aureus*, vancomycin-resistant enterococcus and MDR *Acinetobacter* spp. recovered from 72%, 31% and 17% of samples, respectively. Isolates were transferred from 69% of samples after wiping with sterile water, and from 54% of samples after wiping with 1000 ppm sodium hypochlorite.

Discussion: While moist swabbing failed to detect bacteria from keyboards, pathogens were recovered using enrichment culture. Use of water- or NaOCl-soaked wipes transferred bacteria from most samples tested. This study implies that hospital keyboards situated outside the patient zone commonly harbour dry surface biofilms (DSBs) that offer a potential reservoir for transferable pathogens. While the role of keyboards in transmission is uncertain, there is a need to pursue effective solutions for eliminating DSBs from keyboards.

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https://doi.org/10.1016/j.jhin.2021.02.021
0195-6701/

Introduction

Contaminated environmental surfaces are linked with increased risk of healthcare-acquired infections (HAIs) [1,2]. The clinical environment harbours potentially harmful pathogens, including multi-drug-resistant organisms (MDROs) [3]. Patients are at higher risk of contracting an MDRO when they occupy a room previously occupied by an MDRO-positive patient [2,4]. Indeed, surfaces have been shown to harbour MDROs even when standard cleaning and/or disinfection protocols for rooms with MDRO-infected occupants have been followed [5]. Micro-organisms can persist on surfaces for a prolonged period of time; some bacteria, such as meticillin-resistant *Staphylococcus aureus* (MRSA) or vancomycin-resistant enterococci (VRE), can survive on dried surfaces for >1 year [2]. Extended bacterial persistence in the environment can be attributed to dry surface biofilms (DSBs), which are dynamic microbial communities on dry surfaces [6]. Hu *et al.* reported that 93% of 44 surfaces in intensive care units demonstrated the presence of DSBs, with 52% positive for multi-resistant bacteria [7]. Similar findings reporting the widespread presence of DSBs was also observed by Ledwoch *et al.*, with 95% of 61 hospital items including keyboards, patient folders, hospital commodes etc. colonized with, on average, 18 (range 10—61) different species, including pathogens [8]. The presence of DSBs has been confirmed visually by scanning electron microscopy, and these are recoverable from surfaces despite cleaning with 500 ppm free chlorine solution [7—9].

Surfaces and devices from a patient's immediate environment are not the only potential sources of infection. Frequently touched surfaces in healthcare facilities may facilitate transfer of pathogens even when they are not in close proximity to patients [10]. Healthcare workers may transmit pathogens from surfaces [11], and this is compounded by poor compliance with hand hygiene [12]. Frequently touched surfaces outside the patient zone include objects such as telephones or computer keyboards [13].

Although evidence of contaminated computer keyboards is well established, there are no studies on the transmission of clinically significant micro-organisms from keyboards to hospital staff and patients [14]. Moreover, to the authors' knowledge, the transferability of bacteria from keyboards directly after treatment with a chlorine-releasing agent has not been studied to date. As such, this study investigated the presence of DSBs on 52 routinely cleaned hospital keyboards from four healthcare facilities across the UK, and the potential for bacterial transfer after wiping with sterile water or sodium hypochlorite.

Methods

Sample collection and selection

Used keyboards were collected from a 1000-bed university hospital in Wales, a 500-bed district general hospital in Scotland, a 1700-bed university hospital in England and a dental practice in Scotland. The keyboards were from adult intensive care, acute short stay, acute admission, kidney and transplant, cancer services, haematological malignancies, trauma and orthopaedic units. From each keyboard, keys of the same size with similar English usage frequency (A, E, T and O) were selected at random for swab test and two transfer tests using the Math.random method within the JavaScript programming language in Research Randomizer (Version 4.0) [15]. In total, 52 keys from 13 keyboards were investigated for the presence of DSBs. Scanning electron microscopy analysis was not performed to visualize the DSBs.

Sample pre-treatment

To remove visible dirt and planktonic microbes, all key samples were vortexed (Fisherbrand vortex shaker; Fisher Scientific, Loughborough, UK) three times for 1 min with 30 mL of sterile water in 50-mL polypropylene conical Falcon tubes (ThermoFisher Scientific).

Swab test

A sterile cotton swab (ThermoFisher Scientific, Waltham, MD, USA) was streaked over keyboard keys three times vertically and three times horizontally (Figure 1) with 150 g of pressure. The pressure was chosen based on the force applied by a typing finger (from 0.6 to 1.7 N [16], corresponding to 61 g and 173 g). The swab was then streaked on a tryptone soya agar plate (TSA; EO Labs, Bonnybridge, UK) following the same motion pattern and swab pressure. The sample was presumed to be free of bacteria when no bacterial growth was observed on the TSA plate following overnight incubation at 37°C.

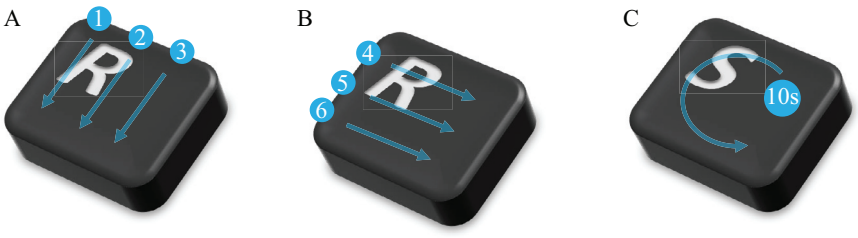

Figure 1. Vertical (A) and horizontal (B) motion of swab on keyboard key during swab test. Clockwise circular motion of wipe on keyboard key as executed by Wiperator (C).

Wiping with sterile water and NaOCl 1000 ppm

NaOCl 1000 ppm solution was prepared by mixing sodium hypochlorite, 10–15% active chlorine solution (ACROS Organics; ThermoFisher Scientific) in distilled water up to the final concentration of 1000 ppm as measured by Pocket Colorimeter (HACH, Manchester, UK) via the N, N-diethyl-p-phenylenediamine method. Sterile distilled water or NaOCl 1000 ppm solution were combined with a HYGEN disposable microfibre cloth (Rubbermaid Products, Epsom, UK), allowing 2.5 mL of liquid per 1 g of wipe. Wiping was performed according to the modified ASTM E2967 test, as in a previous study [17]. Briefly, the Wiperator (Filtaflex Ltd, Almonte, Canada) was used to wipe the keyboard key following a clockwise circular motion (Figure 1), with a wipe soaked in sterile water or NaOCl 1000 ppm, for 10 s with 500 g of pressure. The pressure was chosen based on the force applied during firm surface wipe sampling (3–14 N force [18], corresponding to 306 g and 1428 g). Treated keyboard keys were left for 2 min at room temperature (contact time) prior to transfer testing.

Transfer test

Following wiping with sterile water or NaOCl 1000 ppm, key samples were pressed against Dey-Engley (DE) neutralizing agar (Neogen, Ayr, UK) with 150 g of pressure to imitate a typing finger touch [16]. In total, 25 consecutive depressions were performed for each sample. DE agar plates were incubated at 37°C overnight. A sample was positive for bacterial transfer when at least one depression resulted in bacterial growth [17].

Incubation on selective agars

Following pre-treatment (3x1-min vortexing in 30 mL of sterile water), each key sample was placed in a 50-mL Falcon tube containing 20 mL of TSB and incubated overnight at 37°C. Turbid samples were diluted x10,000 in maximum recovery diluent (Oxoid, ThermoFisher Scientific) and filtered through 0.2-μm Whatman cellulose nitrate membrane filter paper (GE Healthcare UK Limited, Little Chalfont, UK). After filtration, filter papers were placed on selective agar with sterile forceps: PP3056 MRSA agar, PP1723 MacConkey agar, PP3052 multi-drug resistant (MDR) *Acinetobacter* spp. agar and PP3055 VRE agar (E&O Laboratories Limited, Bonnybridge, UK). Growth and appropriate morphology on these selective agars were used to confirm MRSA, MDR *Acinetobacter* spp. and VRE.

Results and discussion

Sampled keyboards had been used for a prolonged period of time – from 6 months up to a few years – depending on the healthcare facility. Following collection, all keyboard samples were visibly dirty (data not shown). Keyboards are challenging to clean due to irregular surfaces and low material compatibility with disinfectant products [19]. Ramphal *et al.* showed that environmental surfaces such as floors, bedding, furniture, computer keyboards and accessories, doorknobs and light switches in healthcare facilities are often poorly cleaned [20].

Swabbing did not obtain bacteria from any keyboard sample (Table I). However, failing to isolate planktonic or loosely attached bacteria does not necessarily equate with surface safety. Once immured in biofilm, it can be challenging to remove bacteria from dry surfaces [21]. It is also debatable whether swabbing, one of the most frequently used techniques to determine surface contamination, is, in fact, the best method for surface screening. It has been shown that bacterial recovery from traditional cotton swabs is unsatisfactory [22]. Bacteria including pathogens reside on surfaces within biofilms [21,23], which are complex communities of micro-organisms. DSBs form and grow on surfaces with limited availability of moisture and nutrients [7,9]. DSBs are less susceptible to

Table I
Detection of bacteria on keyboard key samples by swabbing and transfer tests

Keyboard sample number	Origin	Healthcare facility	Bacteria from DSBs detected (+)/not detected (-)		
			Swab test for bacterial presence[a]	Transfer test after wiping with sterile water[b]	Transfer test after wiping with NaOCl 1000 ppm[b]
1	Wales	1000-bed hospital	-	+	+
2			-	+	-
3			-	-	-
4			-	-	-
5	Scotland	500-bed hospital	-	+	-
6			-	+	+
7			-	-	+
8			-	+	-
9	England	1700-bed hospital	-	-	+
10			-	+	+
11			-	+	-
12	Scotland	Dental practice	-	+	+
13			-	+	+
Total			0/13	9/13	7/13

DSBs, dry surface biofilms.
[a] All samples vortexed three times in 30 mL of sterile water prior to swab test. Swab test performed at 150 g of pressure for 10 s.
[b] All samples vortexed three times in 30 mL of sterile water prior to wiping and transfer test. Wiping with 500 g of pressure for 10 s. Rubbermaid wipe with 2.5 mL of sterile water/NaOCl 1000 ppm solution per g of wipe.

biocides than wet biofilms residing in natural and artificial liquid habitats [24,25].

In contrast to swabbing, almost 70% of samples transferred bacteria when wiped with a sterile cloth moistened with sterile water (Table I). The National Patient Safety Agency advise cleaning keyboards weekly with detergent wipes instead of chlorine-releasing agent [26]. It is therefore likely that hospital keyboards routinely receive detergent-based cleaning alone, as opposed to disinfection, during an outbreak. In most hospitals, protocols are modified to include disinfectants, often a chlorine-releasing disinfectant, when managing MDROs, *Clostridium difficile*, and others including severe acute respiratory syndrome coronavirus-2. However, even if keyboards were treated using chlorine-releasing disinfectants, the findings indicate that this would still not be adequate for comprehensive decontamination. Following wiping with 1000 ppm chlorine, 54% of keys were still contaminated and thus potentially able to transfer bacteria. Studies investigating the ease of bacterial transfer from surfaces contaminated with DSBs to hands remain scarce. Transferability of DSBs has been investigated with *S. aureus* and *Candida auris* artificial in-vitro DSB models [6,17,27], or from hospital surfaces originating from patient rooms [11,28,29]. Ineffective decontamination of hospital surfaces is multi-factorial and includes limited efficacy of disinfectants against bacteria, particularly in DSBs [27], surfaces missed during cleaning [30,31], or inadequate cleaning/disinfection processes on surfaces that are cleaned [32,33]. Moreover, checking that a surface has been properly cleaned/disinfected and is safe to be touched is challenging [34] as no standardized monitoring method has been established [13,22,35]. Swabbing is the usual method, but there is concern about its effectiveness as the recovery of bacteria from cotton swabs may be <25%, mainly due to the low release rate of bacteria from swabs into solid nutrient medium/intermediate diluent [36].

As pointed out by Han *et al.*, establishing a sterile surface is not the main aim of environmental cleaning in hospitals [34]. Nevertheless, cleaning and disinfection of hospital surfaces should decrease the risk of infection [34], so there is concern that DSB bacteria may be transferred from the keyboard keys even after treatment with 1000 ppm chlorine. Some hospitals use ultraviolet-C (UV-C) disinfection technology as part of their terminal cleaning. UV-C has been shown to be effective against major pathogens in hospital settings [37], which includes bacteria that can be found on keyboards [38]. However, in-house data suggest otherwise, and the impact of UV-C in DSB transmission prevention has not been reported to date [39].

Bacteria found on surfaces, notably in DSBs, are not always pathogenic [8]. In the present study, keyboard samples were analysed with selective plates to determine the presence of MDR *Acinetobacter* spp., VRE and MRSA (Figure 2). Among hospitals, the Welsh facility contained the highest percentage of antibiotic-resistant micro-organisms, with 25%, 63% and 88% of samples positive for MDR *Acinetobacter* spp., VRE and MRSA, respectively. Some of the keys sampled from the Scottish hospital were contaminated with MDR *Acinetobacter* spp., VRE and MRSA (10%, 30% and 70%, respectively). MDROs were also detected on keyboard samples from the English hospital, with 13%, 13% and 50% of keys positive for MDR *Acinetobacter* spp., VRE and MRSA, respectively. The Scottish dental practice was the only facility to contain samples free of VRE (no bacterial growth on selective plates tested in this study). This would be expected in an ambulatory clinic, as VRE is more likely among hospitalized patients, particularly those on renal, critical care and haematology wards. Nevertheless, the percentage of MDR *Acinetobacter* spp. and MRSA-positive keyboards in the dental practice was the highest among all healthcare facilities investigated in this study (33% and 100% of dental practice samples were positive for MDR *Acinetobacter* spp. and MRSA, respectively).

The highest prevalence rates of coliforms and non-lactose-fermenting Gram-negative bacterial species were found on samples from the English hospital and Scottish dental practice, with 75% and 100% of MacConkey agar positive for bacterial growth, respectively (Figure 2). Of the samples from the Welsh and Scottish hospitals, 25% and 20% were contaminated, respectively. Other studies have reported keyboard samples from hospitals contaminated with coliforms [14,40], although transferability was not investigated.

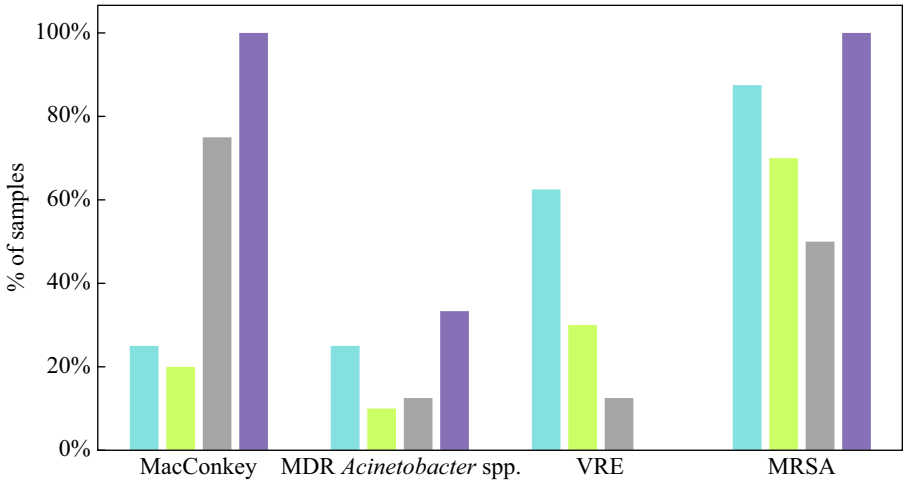

Figure 2. Percentage of hospital keyboard samples indicating positive bacterial growth on MacConkey, multi-drug-resistant (MDR) *Acinetobacter* spp., vancomycin-resistant enterococci (VRE) and meticillin-resistant *Staphylococcus aureus* (MRSA)-selective plates. Blue bars, Welsh hospital; yellow bars, Scottish hospital; grey bars, English hospital; purple bars, Scottish dental practice.

It needs to be mentioned that despite the high sensitivity of selective plates used in this study and additional positive controls using quality control strains, the selective plates may not be entirely selective for a single species from complex biofilms. This constitutes a limitation of this study.

As shown, clinically relevant pathogens from keyboards are still transferable following NaOCl 1000 ppm decontamination, which suggests that current cleaning/disinfection protocols may not be effective for combating DSBs. This study underlines the need for improvement in keyboard decontamination products; it is important for products to demonstrate efficacy against DSBs. Furthermore, devices that are easy to clean should be a preferred choice in hospitals. Keyboards need to be constructed from materials that are compatible with stronger cleaning solutions, and their designs should be free of crevices in order to avoid accumulation of bacteria in inaccessible places, such as beneath the keys.

This study showed that hospital keyboards may be a potential source of infection, with transferable pathogenic bacteria residing in DSBs, including MDR *Acinetobacter* spp., VRE, MRSA, coliforms and non-lactose-fermenting Gram-negative bacteria (Figure 2). These pathogens could not be detected by swabbing, even when keyboard keys were moistened prior to sampling. However, after wiping with sterile water or NaOCl 1000 ppm, bacteria could be identified and transferred from keyboards. It is suggested that these bacteria survive in DSBs which cannot be detected directly by swabbing [8], but wiping disturbs DSBs and enables pathogen transfer. It is clear that further studies on DSBs are needed, as well as finding a product that can control DSBs effectively whilst preventing bacterial transfer.

Conflict of interest statement

KL is employed part-time by GAMA Healthcare Ltd.

Funding sources

None.

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