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

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Summary

Introduction

Healthcare environmental surfaces may be contaminated with microorganisms that cause healthcare-associated infections (HCAIs). Special attention is paid to near-patient surfaces but less so for sites outside the patient zone. 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 multidrug resistant organisms (MDRO) was sought using selective culture.

Results

Moist swabbing did not detect bacteria from any keyboard samples. Use of enrichment broth, however, demonstrated MDRO from most samples. Gram-negative bacteria were recovered from almost half (45%) samples, with methicillin-resistant *Staphylococcus aureus*, vancomycin-resistant enterococcus and MDR-Acinetobacter from 72%, 31% and 17% of samples, respectively. Isolates were transferred from 69% samples after wiping with sterile water, and from 54% samples after wiping with 1,000 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. Our study implies that hospital keyboards situated outside the patient zone, commonly harbour dry surface biofilms (DSB) that offer a potential reservoir for transferable

pathogens. While the role of keyboards in transmission is uncertain, we should pursue effective solutions for eliminating DSB from keyboards.

Introduction

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

Surfaces and devices from a patient's immediate environment are not the only potential source 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], which is compounded by poor hand hygiene compliance [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 transmission of clinically significant microorganisms from keyboards to hospital staff and patients [14]. Moreover, no one has yet investigated transferability of bacteria from keyboard directly following treatment with a chlorine-releasing agent. In this study, we investigated the presence of DSB from 52 routinely cleaned hospital keyboards from four healthcare facilities across the UK. We then studied the potential for bacterial transfer after wiping with sterile water or sodium hypochlorite.

Methods

Sample collection and selection

Used keyboards were collected from a Welsh 1,000-bed university hospital, a Scottish 500-bed district general hospital, a 1,700-bed English university hospital and a Scottish dental practice. Keyboard origin included 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 letter frequency (A, E, T and O) were randomly selected 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 DSB. Scanning Electron microscopy analysis was not performed to visualise the DSB.

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 sterile water in 50 mL polypropylene conical Falcon™ tubes (Fisher Scientific, Loughborough, UK).

Swab test

A sterile cotton swab (ThermoFisher Scientific, Newport, UK) was streaked over keyboard keys 3 time vertically and 3 times horizontally (Figure 1), with 150g pressure. The pressure was chosen based on the force applied by a typing finger (from 0.6 to 1.7N [16], corresponding to 61g and 173g). The swab was then streaked on tryptone soya agar plate (TSA, EO Labs, Bonnybridge, UK) following the same motion pattern and swab pressure. The sample was presumed free from 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 1,000 ppm

NaOCl 1,000 ppm solution was prepared by mixing sodium hypochlorite, 10-15% active chlorine solution (ACROS Organics™, Fisher Scientific, Loughborough, UK) in distilled water up to the final concentration of 1,000 ppm as measured by Pocket Colorimeter™ (HACH®, Manchester, UK) via the N, N-diethyl-p-phenylenediamine (DPD) method. Sterile distilled water or NaOCl 1,000 ppm solution were combined with HYGEN™ disposable microfibre cloth (Rubbermaid, Products, Surrey, UK), allowing 2.5 mL of liquid per 1g of wipe. Wiping was performed according to modified ASTM E2967 test as in a previous study [17]. Briefly, the Wiperator (Filtaflex Ltd, Ontario, Canada) was used to wipe the keyboard key following clockwise circular motion (Figure 1), with sterile water - or NaOCl 1,000 ppm – soaked wipe for 10s with 500g pressure. The pressure was chosen based on the force applied during firm surface wipe sampling (3 to 14 N force [18], corresponding to 306g and 1,428g). Treated keyboard keys were left for 2 min at room temperature (contact time) prior to transfer test.

Transfer test

Following sterile water or NaOCl 1,000 ppm wiping, key samples were pressed against Dey-Engley (DE) neutralising agar (Neogen, Ayr, UK) with 150g pressure, to imitate a typing finger touch [16]. In total, 25 consecutive depressions were performed for each sample. DE agar plate was then incubated at 37°C overnight. The 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 sterile water), each key sample was placed in 50 mL capacity falcon tube containing 20 mL TSB and incubated overnight at 37°C. Turbid samples were diluted x10,000 in maximum recovery diluent (Oxoid, Thermo Scientific™, Loughborough, UK) and filtered through 0.2 µm Whatman™ cellulose nitrate membrane filter paper (GE Healthcare UK Limited, Buckinghamshire, U.K). After filtration, filter papers were placed onto selective agar with sterile forceps: PP3056 methicillin-resistant *S. aureus* (MRSA) agar, PP1723 MacConkey agar, PP3052 Multi-drug resistant (MDR) Acinetobacter agar and PP3055 Vancomycin-resistant Enterococcus (VRE) agar (E&O Laboratories Limited, Bonnybridge, Scotland). Growth and appropriate morphology on these selective agars were used to confirm MRSA, MDR Acinetobacter and VRE.

Results and discussion

Sampled keyboards had been used for a prolonged time period - 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 mice, 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 biofilm [21, 23], which is a complex community of microorganisms. Dry surface biofilm is formed and grown on surfaces with limited availability of moisture and nutrients [7, 9]. DSB are less susceptible to 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 will receive detergent-based cleaning only, as opposed to disinfection, during an outbreak. In most hospitals, protocols are modified to include disinfectants, often a chlorine-releasing disinfectant, when managing MDROs, *C. difficile,* and others including COVID-19. But even if keyboards were treated using chlorine-releasing disinfectants, our findings indicate that this would still not be adequate for comprehensive decontamination. Following wiping with 1,000 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 dry-surface biofilm to hands remain scarce. Transferability of dry surface biofilm has been investigated with *S. aureus* and *C. 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 multifactorial and includes limited efficacy of disinfectants against bacteria – particularly in DSB [27], some surfaces being 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 standardised monitoring method has been established [13, 22, 35]. Swabbing is the usual method, but there is a concern about its effectiveness since the recovery of bacteria from cotton swabs might be less than 25%; mostly 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 infection risk [34], so there is concern that DSB bacteria may be transferred from the keyboard keys even after 1,000 ppm chlorine treatment. Some hospitals utilise ultraviolet-C (UV-C) disinfection technology as a 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 yet been reported [39].

Bacteria found on surfaces, notably in DSB, are not always pathogenic [8]. Here, 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 microorganisms, with 25%, 63% and 88% of samples positive for MDR-*Acinetobacter* spp., VRE and MRSA, respectively. Some of the keys sampled from 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 hospitalised patients, particularly those on renal, critical care and haematology wards. Nevertheless, the percentage of MDR-*Acinetobacte*r 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 and MRSA, respectively).

Figure 2. The percentage of hospital keyboard samples indicating positive bacterial growth on MacConkey, MDR Acinetobacter, VRE and MRSA selective plates. Keyboard samples from ■ Welsh Hospital (WH), ■ Scottish Hospital (SH), ■ English Hospital (EH), and ■ Scottish Dental practice (SD)

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

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

As shown, clinically relevant pathogens from keyboards are still transferable following NaOCl 1,000 ppm decontamination, which suggests that current cleaning/disinfection protocols might not be effective for combating DSBs. The study underlines the need for improvement in keyboard decontamination products: it is important for products to demonstrate efficacy against dry surface biofilms. Furthermore, devices that are easy to clean should be a preferred choice in hospitals. Keyboards need to be constructed from material that is compatible with stronger cleaning solutions and their design should be free from crevices to avoid accumulation of bacteria in inaccessible places, such as underneath the keys.

Our study showed that hospital keyboards might be a potential source of infection, with transferable pathogenic bacteria residing in dry surface biofilms, including MDR-*Acinetobacter* spp., VRE and 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 1,000 ppm, bacteria could then be identified and transferred from keyboards. We suggest that these bacteria survive in DSB which cannot be directly detected by swabbing[8], but wiping disturbs DSB to enable pathogen transfer. It is clear that further studies on DSB are needed, as well as finding a product that can effectively control DSB whilst preventing bacterial transfer.

Conflict of interest

KL is employed part-time by GAMA Healthcare Ltd

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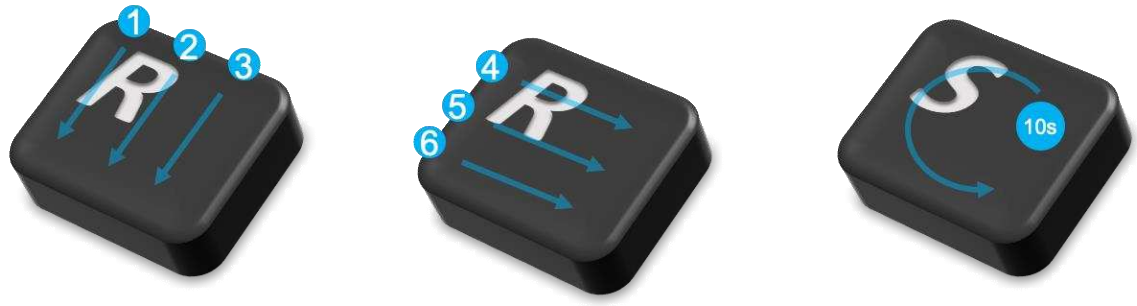
Table I. Detection of bacteria on keyboard key samples by swabbing and transfer tests.

Keyboard sample number	Origin	Healthcare facility	Bacteria from DSB detected (+) / not detected (-)		
			Swab test for bacterial presence[1]	Transfer test after wiping with sterile water[2]	Transfer test after wiping with NaOCl 1,000 ppm[2]
1	Wales	1,000-bed hospital	-	+	+
2			-	+	-
3			-	-	-
4			-	-	-
5	Scotland	500-bed hospital	-	+	-
6			-	+	+
7			-	-	+
8			-	+	-
9	England	1,700-bed hospital	-	-	+
10			-	+	+
11			-	+	-
12	Scotland	Dental practice	-	+	+
13			-	+	+
Total			0/13	9/13	7/13

[1] All samples vortexed 3 times in 30 mL sterile water prior to swab test. Swab test performed at 150 g pressure for 10s

[2] All samples vortexed 3 times in 30 mL sterile water prior to wiping and transfer test. Wiping with 500g pressure for 10s. Rubbermaid wipe with 2.5 mL of sterile water/NaOCl 1,000 ppm solution per g of wipe.

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).



A. Vertical motion (swab test)

B. Horizontal motion (swab test)

C. Clockwise circular motion (wipe test)

Figure 2. The percentage of hospital keyboard samples indicating positive bacterial growth on MacConkey, MDR Acinetobacter, VRE and MRSA selective plates. Keyboard samples from ■ Welsh Hospital (WH), ■ Scottish Hospital (SH), ■ English Hospital (EH), and ■ Scottish Dental practice (SD)