BMJ Open

# What's on your keyboard? A systematic review of the contamination of peripheral computer devices in healthcare settings



| | |
|---|---|
| Journal: | *BMJ Open* |
| Manuscript ID | bmjopen-2018-026437 |
| Article Type: | Research |
| Date Submitted by the Author: | 04-Sep-2018 |
| Complete List of Authors: | Ide, Nicole; University of Washington, Family Medicine<br>Frogner, Bianca; University of Washington, Family Medicine<br>LeRouge, Cynthia; Florida International University, Department of Information Systems & Business Analytics<br>Vigil, Patrick; Pacific Northwest University<br>Thompson, Matthew; University of Washington, Department of Family Medicine |
| Keywords: | Infection control < INFECTIOUS DISEASES, Health & safety < HEALTH SERVICES ADMINISTRATION & MANAGEMENT, contamination, healthcare-acquired infection, nosocomial infection, keyboard |
| | |

# What's on your keyboard? A systematic review of the contamination of peripheral computer devices in healthcare settings

Nicole Ide[1], Bianca K. Frogner[1], Cynthia M. LeRouge[2], Patrick Vigil[3], Matthew J. Thompson[1]

[1] Department of Family Medicine, University of Washington, Seattle, WA 98195-4696 USA

[2] Department of Information Systems & Business Analytics, Florida International University, Miami, FL 33199, USA

[3] Pacific Northwest University, Yakima, WA 98901, USA

**Corresponding Author:**

Matthew J. Thompson, mjt@uw.edu, +1-206-616-8149

University of Washington, Family Medicine, Box 354696, Seattle WA 98195-4696

**Word Count:** 3,466

**Keywords**: contamination, healthcare-acquired infections, Nosocomial Infection, keyboards, cross infection, infection control

**ABSTRACT**

**Objective** To determine the extent and type of microbial contamination of computer peripheral devices used in healthcare settings, evaluate the effectiveness of interventions to reduce contamination of these devices, and establish the risk of patient and healthcare worker infection from contaminated devices.

**Design** Systematic Review

**Methods** We searched four online databases: MEDLINE, CINAHL, Embase, and Scopus for articles reporting primary data collection on contamination of computer-related equipment (including keyboards, mice, laptops, and tablets) and/or studies demonstrating the effectiveness of a disinfection technique. Pooling of contamination rates was conducted where possible, and narrative synthesis was used to describe the rates of device contamination, types of bacterial and viral contamination, effectiveness of interventions, and any associations between device contamination and human infections.

**Results** Of the 4,432 records identified, a total of 75 studies involving 2,804 computer devices were included. Of these, 50 studies reported contamination of computer-related hardware, and 25 also measured the effects of a decontamination intervention. The overall proportion of contamination ranged from 24% to 100%, and the most common microbial contaminants were skin commensals, but also included potential pathogens including MRSA, C. difficile, VRE, and E. coli. The most evidence for effective decontamination interventions included wipes/pads using isopropyl alcohol, quaternary ammonium, Chlorhexidine, or dipotassium peroxodisulphate, UV-light emitting devices, enhanced cleaning protocols, and chlorine/bleach products. However, results were inconsistent, and there was insufficient data to demonstrate comparative effectiveness. We found little evidence on the link between device contamination and patient/healthcare worker colonization or infection.

**Conclusions** Computer peripheral devices are frequently contaminated and have the potential to contribute to the transmission of pathogens to patients and staff. Additional studies measuring the incidence of healthcare-acquired infections from computer hardware, the relative risk that they pose to healthcare, and evidence for the most effective and practical cleaning methods are needed.

**Strengths and limitations of this study:**

- This is the first systematic review on the level of contamination of computer peripheral devices used in clinical care as well as effectiveness of interventions used to decontaminate these surfaces.
- We searched four major online databases during the literature search and hand searched references of included studies and relevant review articles
- Reporting of this review adhered to the PRISMA guidelines
- The ability to perform meta-analysis was limited by the heterogeneity among included studies

## INTRODUCTION

The annual number of healthcare-acquired infections (HAIs) in U.S. acute care hospitals is estimated at approximately 722,000, or 4% of inpatients.[1] HAIs lead to longer admissions, more frequent re-admissions, and poorer patient outcomes including increased mortality.[2, 3] The U.S. Centers for Disease Control and Prevention (CDC) estimates that preventing HAIs in the U.S. would result in annual direct savings of between $5.7 and $31.5 billion.[4] Studies to date have largely focused on hospital settings, thus the frequency of consequences of HAIs in outpatient settings is poorly described.

Between 20% and 40% of HAIs result from cross-infection via hands of personnel, and another 20% from other environmental contamination.[5] Contamination of environmental surfaces in healthcare settings is a well-known source of nosocomial infection, and several pathogens have been identified on surfaces in hospital environments, including methicillin-resistant Staphylococcus aureus (MRSA), Clostridium difficile (C. diff), Acinetobacter baumannii, vancomycin-resistant enterococci (VRE), Pseudomonas aeruginosa, Norovirus, and gram-negative bacteria.[6-9] Nosocomial pathogens often originate from infected patients who come into contact with the surfaces surrounding them, particularly “high-touch surfaces”, and are then transferred to other healthcare workers’ or patients’ hands.

Several studies looking at healthcare workers’ personal devices (mobile phones or PDAs), clothing (neckties, white coats, etc.), and a variety of other objects (stethoscopes, blood pressure cuffs, telephones, faucets, bedrails, etc.) have found significant rates of environmental contamination.[6, 10, 11] However, the importance of contamination related specifically to computer keyboards, mice, and other computer peripherals is less well established despite their ubiquitous use in hospital and ambulatory healthcare settings.

We therefore conducted a systematic review to determine the extent to which computer keyboards, mice, and other computer peripheral devices have been identified as being a source of contamination in

clinical settings. We examine the type and prevalence of microbial contamination, and the settings in which these contaminated devices have been addressed. We also determined the effectiveness of interventions that aim to reduce contamination of these devices, and any evidence linking clinical consequences of HAI related to computer keyboards/peripherals among patients and healthcare workers.

## METHODS

We report this systematic review in accordance with the PRISMA guidelines, an evidence-based minimum set of items recommended for reporting of systematic reviews.[12] A PRISMA checklist can be found in **Supplementary File 1.**

### Search strategy

A total of four databases were included in our search: MEDLINE, CINAHL, Embase, and Scopus. We developed two major categories of search terms that were used in various combinations to search the databases. Firstly, terminology related to peripheral and external computer hardware devices, such as mice and keyboards. Secondly, terminology related to infection, contamination or disinfection (**Supplementary File 2)**. We conducted automated searches databases from January 1, 1990 through July 14, 2017. We limited the search to this time frame due to the low rates of computer use in clinical settings prior to 1990. Additionally, we manually searched the references of included studies and relevant review articles to identify further eligible studies, and where possible, we contacted authors to obtain full texts of abstracts if not available online.

### Eligibility criteria and study selection

We included studies that met the following criteria: a) conducted in any type of healthcare setting in a high- or upper middle-income country,[13] b) investigated keyboards, mice, mouse pads, computer

touch screens, laptops, and iPads/tablet computers, c) reported primary data collected through experimental, quasi-experimental, or observational study designs, d) reported contamination rates of computer-related equipment and/or demonstrated the effectiveness of disinfection technique(s), e) reported any association between contamination of computer-related equipment and infection or colonization of patients/healthcare workers, and f) written in English language.

We excluded studies which were not conducted in a healthcare setting or were conducted in low- or lower middle-income countries (where pathogenic microbes are potentially different to those found in high- or upper middle-income countries), tested computer related equipment with in vitro experiments, reported solely data on environmental surfaces other than computer-related hardware, or assessed healthcare worker knowledge or compliance with disinfection or hand-washing protocols. We excluded all studies that only provided an abstract.

After searching the four databases, we uploaded articles to EndNote X8 and removed any duplicates. One reviewer (NI) screened titles and abstracts to remove clearly irrelevant studies. Two reviewers (NI and MT) independently screened the full text of all remaining articles to determine final eligibility, and resolved any discrepancies through discussion and consensus.

**Data extraction and quality assessment**

Using a standardized form in Microsoft Excel, a single reviewer (NI) extracted the following data from each included article: country and clinical setting, study design, sampling frame and size, microbiological sampling method, microbiological identification method, outcome measure(s), intervention definition (if any), comparison (if any), ongoing decontamination methods (if any), and results (baseline contamination rates, baseline pathogens detected, post-intervention contamination rate). Extracted data were checked for accuracy by a second author (MT), and disagreements were resolved prior to analysis.

Two authors (NI and MT) independently assessed the methodological quality and risk of bias using checklists we developed based on The National Heart, Lung, and Blood Institute's (NHLBI) study quality assessment tool [14] as well as criteria developed in a relevant systematic review by Livshiz-Riven et al. which assessed the relationship between contamination and noninvasive portable clinical environmental surfaces.[15] To assess risk of bias for each outcome, we developed two separate checklists: one for studies reporting only baseline contamination and another for studies that included an intervention. We looked at the quality of individual studies and assessed the risk of bias on the basis of study design, objectives, sampling strategy, microbial detection methods, outcome measurement and reporting, and confounding variables. For studies of decontamination interventions, we also assessed intervention characteristics and comparisons or controls. Each assessment item was scored as "Yes", "No", or "Unclear". The overall risk of bias of the body of evidence was considered in interpretation of findings of the review.

**Summary measures**

For studies reporting contamination of peripheral computer-related hardware devices, we present findings as the proportion of devices contaminated, using definitions of contamination as reported in individual studies. For studies reporting effectiveness of a decontamination intervention, we present findings as a change (or percentage change) in contamination rates following the intervention, as reported by the respective authors. We explored whether there were differences in contamination rate between clinical settings, countries, or types of devices. We intended to use meta-analysis to pool results, but due to heterogeneity in study design, interventions, and outcomes reported, this was not possible. A simple pooled mean of baseline contamination of the studies which included an overall baseline rate of device contamination was calculated.

### Patient and public involvement

Neither patients nor the public were involved in the development of the research question or study design for this systematic review. Results will be made available to the public by publishing this study in a peer-reviewed, open access journal.

## RESULTS

### Study selection

Our search identified 4,416 records, with an additional 24 identified through a manual search. After removing duplicates, we screened the remaining 3,920 articles based on our inclusion criteria. Of these, 174 were selected for full-text review, of which 99 did not meet our criteria and were excluded, leaving a total of 75 studies in the final analysis (**Figure 1**).[16-90]

### Study characteristics

Of the 75 included studies (**Supplementary File 3**), only one was published prior to year 2000, with another 27 studies published between 2000-2009, and 47 studies published 2010 onwards. Most were conducted either in the USA or Canada (26) or Europe/Central Asia (28), followed by Southeast/East Asia or the Pacific (12), Middle East (4), South America (4), and South Africa (1).

The vast majority (63) of studies were conducted only in hospitals, including intensive care units (ICU) (12 conducted solely in ICU and an additional 17 studies included ICU as one of their settings), emergency department (ED) (11), and operating rooms (OR) (8). A further 12 studies were conducted in a variety of other clinical settings, including dental clinics or dental hospital, radiology settings, an outpatient ophthalmology clinic, a pharmacy practice, and two were in mixed hospital and outpatient settings.

Overall, the included studies provided data on a total of 2,804 devices, including 1,482 keyboards, 665 computer stations, and 398 mice or mouse pads. Nineteen studies did not explicitly state the number of devices tested or only reported the total number of samples taken. Keyboards were the most commonly studied peripheral computer device, with 42 studies testing keyboards alone and another 22 testing a combination of keyboards plus mice. Fewer tested tablets (5) or mice alone (2). The numbers of devices sampled ranged from a single keyboard up to 282 computer stations (keyboards plus mice).

The majority of studies (50) reported primarily on device contamination rates (mostly using cross-sectional samples).[17-23, 26, 29, 32-36, 38, 41-46, 49, 50, 52-56, 60, 62, 64-66, 68-76, 81-86, 90] Another 25 studies used interventional designs;[16, 24, 25, 27, 28, 30, 31, 37, 39, 40, 47, 48, 57-59, 61, 63, 67, 77-80, 87-89] most reported contamination rates before and after a disinfection or cleaning process (and therefore also contributed data on baseline contamination rates). One study only reported contamination post-intervention,[61] and another two reported only on an association between device contamination and patient colonization rates.[63, 88] Of the 25 studies reporting interventions, most used pre-post designs (17), with a smaller number (8) using controlled trials, post-intervention study, cross-over, or prospective comparative analysis. A variety of methods were used to measure effectiveness, including change in rate of overall contamination (11), change in rate of specific pathogens (5), change in colony forming unit (CFU) values (3), reduction in both rates and CFU values (2), rate of keyboards with contamination over 500 CFU (1), number of acquired colonizations pre- and post-intervention (1), patient acquisition of MRSA (1), and contamination rate for post-intervention phase only (1).

**Prevalence of baseline contamination**

A total of 71 studies provided data on levels of device contamination. Of these, 26 presented an overall proportion of microbial contamination (**Table 1**), with contamination rates ranging from 24% to 100%.

Of these 26 studies, 21 reported the proportion of devices contaminated, while five reported the proportion of collected swabs that were contaminated. Of the 21 studies reporting device contamination, the pooled mean contamination rate was 96.7% (range 80% to 100%).

**Table 1: Studies Reporting the Proportion of Computer Devices Contaminated**

| AUTHOR, YEAR | SETTING | DEVICE AND NUMBER | PROPORTION CONTAMINATED |
|---|---|---|---|
| **BURES 2000** | ICU (patient rooms, nurse + doctor stations)<br>USA | 10 keyboards<br>(80 total swabs) | 19/80 (24%) |
| **CODISH 2015** | Internal medicine wards and ICU<br>Israel | 81 keyboards + 81 mice | Internal medicine: 92/92 (100%)<br>ICU: 62/70 (88.6%)<br>Total: 154/162 (95.1%) |
| **CORDEIRO 2015** | ICU in medium sized hospital<br>Brazil | 6 keyboards<br>(12 total swabs) | 6/6 (100%) |
| **DE GROOD 2012** | Medical, surgical, ICU units in 4 urban hospitals<br>Canada | 2 studies:<br>1) 230 keyboards<br>2) 10 Cleankeys keyboards | 1) 229/230 (99.6%) contaminated with CNS, Micrococcus spp., diphtheroids, Bacillus spp. or alpha streptococci.<br>And: 67% keyboards positive with solid agar and broth any one cultures (MSSA, MRSA, Enterococcus (non VRE and VRE), GNB, C. diff., Yeast, fungus)<br>2) 10/10 (100%) |
| **DUSZAK 2014** | outpatient radiologist workstations in 2 hospitals in 2 U.S. states | 7 mice | 7/7 (100%) |
| **GOSTINE 2016** | ICU<br>USA | 40 keyboards<br>(203 total swabs) | 193/203 (95.1%) |
| **GRAY 2007** | ED at tertiary referral hospital<br>Northern Ireland | 7 mice<br>(63 total swabs) | 54/63 (85.7%) |
| **HASSAN 2014** | Staff rooms, computer labs, internet centers in a teaching hospital<br>Iraq | 150 keyboards and 100 mice | 242/250 (99.2%) |
| **HONG 2012** | ED of 3 teaching hospitals<br>South Korea | 56 keyboards and 56 electronic | 103/112 (92.0%) |
| **KARBASIZADE 2014** | Medical wards of various hospitals<br>Iran | 65 keyboards | 64/65 (98.5%) |
| **KEERASUNT-ONPONG 2017** | Patient care areas in general medical wards, ICU in a hospital<br>Thailand | 26 keyboards | 25/26 (96.2%) |
| **KHAN 2015** | two large academic institutions, medical centers<br>USA | 106 portable electronic devices<br>(93 iPads/ tablet) | 100% had at least 1 positive culture from screen or cover. |

| AUTHOR, YEAR | SETTING | DEVICE AND NUMBER | PROPORTION CONTAMINATED |
|---|---|---|---|
| **MARTIN 2011** | ICU and ED in pediatric hospital USA | 24 terminals (keyboards/ Mouse/Pad) | 23/24 (96%) |
| **MESSINA 2013 (B)** | Various units within 3 hospitals Italy | 50 keyboards | With PCA 36°C - 49/50 (98%) With PCA 22°C - 33/50 (66%) |
| **PATEL 2010** | 4 different areas of a dental hospital (2 student study areas, 2 clinics) UK | 8 keyboards | 100% contaminated with variety of microorganisms including S. aureus, CNS, GNR and cocci |
| **RICHARD 2017** | Orthopedic OR USA | 6 keyboards | 100% |
| **RUTALA 2006** | Burn ICU, cardiothoracic ICU, nursing units USA | 25 keyboards | 25 keyboards (100%) had growth of 2 or more microorganisms |
| **SCHULTZ 2003** | VA hospital: areas close to patients in high use areas of the acute, ambulatory, and long term care areas. USA | 100 keyboards | 95 of 100 (95%) |
| **SHAIKH 2016** | Lab and medical wards USA | 25 keyboards | 20/25 (80%) including GNB, C. difficile, Enterococcus spp, or S. aureus |
| **SMITH 2006** | Medical, surgical, family practice programs USA | 60 notebook keys and grips (120 total swabs) | 52/120 cultures (43%) contaminated. Significant pathogens found in only 1.7% of cultures (MSSA and Serratia species) |
| **SWEENEY 2009** | Various clinical wards and ED UK | 68 computer terminals (keyboards/mice) | 67/68 (98.5%) |
| **TAN 2013** | 2 open wards in 800 bed acute care hospital Singapore | Unknown number of keyboards 6 total samples | 6/6 (100%) |
| **WAGHORN 2005** | General medical, general surgical, orthopedic, care of the elderly, dermatology and pediatric wards, ICU, ED, OPD, and theatre suite. UK | 48 keyboards | 100% grew organisms of some kind. 79% of sampled computers grew either moderate or heavy numbers of organisms. |
| **WESTERWAY 2017** | Ultrasound units in public hospital and private practice Australia | 10 ultrasound keyboards | 100% of samples had 10 or more colonies (highest level of contamination) |
| **WILSON 2006** | ICU - bedside and nurse station UK | 17 keyboards | 100% contaminated with at least one species |
| **YUN 2012** | Patient care rooms in burn ICU and orthopedic ward USA | Unknown number of devices (total 32 samples from keyboards/mice) | 32/32 (100%) |

C. diff. = Clostridium difficile, CNS = Coagulase-negative staphylococcus, ED = Emergency department, GNB = Gram Negative Bacilli, GNR = Gram Negative Rods, ICU = intensive care unit, MRSA = Methicillin-resistant Staphylococcus aureus, MSSE = Methicillin-susceptible Staphylococcus epidermidis, OPD= outpatient department, OR = operating room, PCA = Plate count agar, S. aureus = Staphylococcus aureus, VRE = Vancomycin-resistant Enterococcus

A further 12 studies reported overall contamination only as CFU (**Supplementary File 4**), and another 10 reported contamination using a variety of other methods, such as proportion of devices with multiple bacterial species identified, mean bacterial counts, aerobic colony counts (ACC), or adenosine triphosphate (ATP) values/failures (**Supplementary File 5**). A further 23 studies reported baseline contamination of only a single or few specific pathogens: 20 as a proportion (%) of each pathogen, one presented total bacterial counts (mean ± SD), and two reported the existence of specific pathogens without quantifying them (**Supplementary File 6**).

The range of overall contamination was wide: while most studies found a contamination rate of 80%-100%, Bures et al. reported a rate of 24% in a study of keyboards in ICU patient rooms and nurse/doctor stations,[20] while Smith et al. reported a rate of 43% on notebook computers from medical, surgical, family practice programs.[78] However, we were unable to determine differences in contamination rates between clinical settings, countries, or types of devices due to insufficient data.

**Type of microbial contamination**

The specific pathogens isolated from keyboards or other computer devices was reported in 63 studies. Of these, 49 reported the proportion of devices contaminated with specific types of bacteria (**Supplementary File 7**). The most frequent microbial contaminants were skin commensal bacteria, but contamination with a variety of potentially pathogenic bacteria was also reported. The most frequent potential pathogens identified included Staphylococcus aureus (S. aureus) and MRSA, but this depended on whether studies set out to detect all microbe or pathogens, or only specific organisms. Of the studies reporting contamination with S. aureus, the mean contamination rate was 28% (range 1% – 94%). Mean rates of contamination with MRSA was 14% (range 0%-100%), VRE at 3.7% (range 0%-12%), and C. Diff at 8.0% (range 0%-28%).

**Effectiveness of decontamination interventions**

Twenty-five studies evaluated the effectiveness of disinfection or cleaning interventions on the level of device contamination. Of these, 14 reported statistically significant reductions in contamination following the intervention **(Table 2)**. These included seven studies using wipes/pads with isopropyl alcohol, quaternary ammonium, Chlorhexidine, or dipotassium peroxodisulphate;[16, 24, 31, 37, 47, 67, 89] three studies using UV light;[39, 57, 77] two studies using putty cleaning compound;[58, 59] one study with an enhanced cleaning protocol (including glove use);[63] and one study using a keyboard with a cleaning alarm.[87]

**Table 2: Studies Reporting Interventions with Significant Reduction in Contamination of Computer Peripheral Devices**

| STUDY | OUTCOME MEASURES | INTERVENTION METHOD | BASELINE CONTAMINATION | POST-INTERVENTION CONTAMINATION |
|---|---|---|---|---|
| **ALBRECHT 2013** | Total bacterial load | Isopropanol wipes using 6-step disinfection process guided by deBac-App. Control cleaned with new, dry "soft, lint-free cloth" | 1842 total CFU found on iPads in the clinical setting (162 median CFU) | Clinical setting: 98.1% reduction *(P=0.001)*<br>Nonclinical setting: 99.4% reduction *(P=0.001)*.<br>Control reduction rate 51.1% (p-value not reported) |
| **CODISH 2015** | Total bacterial load | MEDIWIPES (alcohol based) vs. TriGene (quaternary ammonium based). Each device decontaminated 3x/day | Internal medicine: 92/92 (100%)<br>ICU: 62/70 (88.6%)<br>Total: 154/162 (95.1%) | Internal medicine: 76/92 (82.6%)<br>ICU: 31/70 (44.3%)<br>Total: 107/162 (66%)<br>*P<0.001 for both Internal Med and ICU* |
| **DUSZAK 2014** | Total bacterial load | "Chlorascrub" pads (chlorhexidine gluconate and isopropyl alcohol) | Bacterial growth found on 100% of computer mice.<br>Mean colony counts: 46.1 ± 58.1 | "Demonstrable bacterial colonization was completely eradicated" for all 4 mice (100% reduction). |
| **FUKADA 2008** | Total bacterial load | Cotton cellulose sheet dampened with ethyl alcohol – *intervention only conducted in the OR* | Mean bacterial counts (SD):<br>OR: 333 (141)<br>ICU: 1015 (501)<br>Consulting room and OPD reception area: 1113 (1420) | In the OR: Mean (SD) total bacteria counts reduced significantly (from 333 (141) to 35 (67) cfu/mL)<br>*P< 0.05* |
| **GOSTINE 2016** | Total bacterial load | UV Angel Desktop lamps, set to 3-, 5-, 6-, and 10-min cycles | 193/203 (95.1%) samples, median of 120 CFUs per keyboard | 13/218 (6%) samples contaminated, a >99% reduction based on median CFU values (120 pre, 0 post). *P<0.0001* |
| **JONES 2015** | Total bacterial load | CHG spray (chlorhexidine gluconate, isopropyl alcohol) vs. TF spray (chlorine dioxide-based) | 57% of keyboards had contamination of >500 CFU (Included: Bacillus sp, CNS, micrococci, diphtheroids) | 2% of keyboards had a contamination of >500 CFU (*P ≤ 0.001)*<br>(only bacterial isolate was bacillus spp.) |
| **MARTIN 2011** | Total bacterial load | Keyboards with Vioguard UV light irradiation vs. identical control keyboards not exposed to UV light irradiation. | 23/24 (96%) had bacteria isolated | 8/24 (33%) had bacteria isolated. *P =0.001*,<br>(Primarily gram-positive human flora and gram-negative environmental flora. S aureus and P aeruginosa isolated from 2 control keyboards) |

| STUDY | OUTCOME MEASURES | INTERVENTION METHOD | BASELINE CONTAMINATION | POST-INTERVENTION CONTAMINATION |
|---|---|---|---|---|
| **MESSINA 2013 (A)** | Total bacteria count of: Staph., E. coli, Pseudomonas, total coliform bacteria, Acinetobacter, C. diff | Putty cleaning compound (ethanol 29%) with malleable-elastic consistency | Total microbial load *(at 2 different incubation temperatures):*<br>36°C: 26/27 (96.3%), CFU: 512<br>22°C: 25/27 (92.6%), CFU 557<br><br>Acinetobacter spp: 1 (3.7%)<br>E.coli: 11 (40.7%)<br>Coliforms: 21 (77.8%)<br>Enterococci: 4 (14.8%)<br>Staphylococci: 25 (92.6%)<br>MRSA: 6 (22.2%)<br>Molds: 20 (74.1%) | 36°C: 2/27 (7.4%), CFU: 3<br>22°C: 4/27 (14.8%), CFU: 18<br><br>Significant reductions in:<br>Coliforms: 2 (7.4%) *p< 0.0001*<br>Staphylococci: 1 (3.7%) *p< 0.0001*<br>Molds: 1 (3.7%) *p< 0.0001*<br>E.coli 0%, *p= 0.001*<br>*Borderline or non-significant reductions in:*<br>Enterococcus 0%: p= 0.045,<br>MRSA 0%: p = 0.014 |
| **MESSINA 2013 (B)** | Total bacterial load | Putty cleaning compound (ethanol 29%) with malleable-elastic consistency | Total microbial load: *(at 2 different incubation temperatures):*<br>36°C: 49/50 (98%)<br>22°C: 33/50 (66%)<br><br>E. coli: 17/50 (34%)<br>Coliforms: 39/50 (78%)<br>Enterococci: 5/50 (10%)<br>Staphylococci: 47/50 (94%)<br>MRSA: 8/50 (16%)<br>Molds: 26/50 (52%) | 36°C: 8/50 (16%)<br>22°C: 8/50 (16%)<br><br>Coliforms: 1 (2%)<br>Staphylococci: 2 (4%)<br>Molds: 1 (2%)<br>*Significant differences for all (p<0.001) after disinfection* |
| **NEELY 1999** | Detection of Acinetobacter species | Enhanced cleaning policy: required to wear gloves before using computer, plastic keyboard covers cleaned daily. | 13 acquired colonizations and 16 total colonizations of A. baumannii in 5 months pre-intervention | 10 acquired colonizations and 34 total colonizations of A. baumannii in 19 months post-intervention.<br><br>*The number of acquired A. baumannii colonizations post- intervention were significantly less than pre-intervention (P<.05).* |
| **PATEL 2010** | Total bacterial load | 70% isopropanol wipes vs. Virkon (dipotassium peroxodisulphate) | 100% contaminated with bacteria including S. aureus, coagulase negative staphylococci, Gram-neg rods and cocci. | 100% of C. albicans, P. aeruginosa and S. sanguinis removed<br>99.9% of S. epidermidis removed<br>96% of all the other organisms removed<br>*The number of organisms recovered after the intervention were significantly reduced (P< 0.001)* |
| **SHAIKH 2016** | Total bacterial load | UV Angel system | 20/25 (80%) contaminated with any potential pathogen, including gram-negative bacilli, C. diff, Enterococcus, or S. aureus. | 5/25 (20%) contaminated with any potential pathogen (*P = 0.0001)*<br>Total aerobic and facultative bacteria: 18/25 (72%) *(P=0.0006)* |
| **WILSON 2008** | Detection of S. aureus, Acinetobacter sp. | Medigenic keyboard (alarm when cleaning required), anonymous keyboard, vs standard keyboards | Fr Medigenic keyboards, baseline contamination rates ranged from 38-65 CFU, depending on alarm interval. Included: MRSA, Acinetobacter | Total viable count on Medigenic keyboards with alarm lower than other two types of keyboards. Median CFU reduced from 38 to 5. *P<0.0001* |
| **XU 2017** | Detection of MRSA | Cotton cloth and bucket system vs. disinfectant wipes | 7/19 (36.8%) keyboards and mice positive for MRSA. | 2/206 (1%) positive for MRSA. *P < 0.001* |

Abbreviations: C. diff. = Clostridium difficile, CFU = colony forming unit, ICU = intensive care unit, MRSA = Methicillin-resistant Staphylococcus aureus, OPD= outpatient department, OR = operating room, S. aureus = Staphylococcus aureus, SD = Standard deviation.

A further eight studies reported reductions in contamination from interventions **(Supplementary File 8)**, but reductions were not statistically significant,[78] not tested using statistical tests,[28, 48, 79, 80] or did not apply the statistical tests specific to data from the computer devices.[27, 30, 40] Effectiveness of interventions in an additional two studies was unclear due to poor reporting of baseline and/or post intervention contamination rates **(Supplementary File 8)**.[25, 61]

**Association between device contamination and clinical infection**

Only five included studies examined the association between device contamination and infection or colonization of patients/healthcare workers (**Supplementary File 9**). Of these, three reported an association, showing that the decontamination intervention was associated with reductions in the rate of MRSA infections,[27] VRE,[40] and Acinetobacter colonizations.[63] However, the link between association and causation in these studies was unclear and open to bias. One study showed that even though 12.5% of positive blood cultures matched the organisms growing from surveillance sites, this correlation was not significant,[70] and one showed no effect of a cleaning intervention on patient acquisition of MRSA.[88]

**Quality Assessment**

For studies that reported contamination rates, sampling methods were often convenience-based, and only six used a power calculation to guide sample size. In 19 studies, the number of included devices was not explicitly stated, and denominators were reported inconsistently. In 44 out of 75 studies, selection criteria for the devices were not given, were not clearly described or implemented consistently. In 29 of the 50 studies that only measured prevalence, samples were obtained at a single time point. Only four of the studies that reported effectiveness of decontamination interventions were controlled trials, with most using cross-sectional or pre-post designs. Reporting of effectiveness of interventions using statistical testing was poor or inconsistent. Few studies were designed in such a way that patient

outcomes could be measured, that is, the direct impact of contamination on HAI. Reporting of results was frequently poor, with only 26 studies reporting the overall number and percentage of computer-related devices with bacterial contamination. Of the 50 studies reporting only baseline contamination, only 10 studies provided a confidence interval or mean/median CFU, ATP or relative light unit (RLU) value of keyboards or computer peripherals sampled. Full risk of bias tables can be found in **Supplementary File 10.**

## DISCUSSION

To our knowledge, this is the first systematic review on the level of contamination of computer peripheral devices as well as effectiveness of interventions used to decontaminate these surfaces. This review fills an important gap and provides substantial evidence from a total of 2,804 devices that computer peripheral devices, particularly keyboards, are potential reservoirs of infective pathogens. The overall proportion of contamination ranged from 24% to 100%. Collectively, studies found a 96.7% contamination rate of keyboards sampled. Moreover, contamination of keyboards and other computer peripherals is not limited to skin commensal bacteria, but includes potential pathogenic bacteria such as MRSA, C. difficile, VRE, and E. coli. Multiple interventions have been tested in attempts to decontaminate computer devices and keyboards, and several appear effective at reducing the overall level of contamination, including: wipes/pads using isopropyl alcohol, quaternary ammonium, Chlorhexidine, or dipotassium peroxodisulphate, UV-light emitting devices, enhanced cleaning protocols, and chlorine/bleach products. However, results were inconsistent and there was insufficient data to provide robust recommendations on which method(s) are most effective.

Current data are mostly limited to hospital settings. Almost all (63) of the included studies were conducted solely in hospitals, with a particular focus on ICUs. Only a small number of studies were conducted solely in ambulatory or outpatient settings.

**Comparison to existing literature**

Our findings are consistent with a variety of literature on the potential contribution of contaminated hospital surfaces to human infection. Not only can environmental surfaces harbor dangerous pathogens, but evidence shows that pathogens such as MRSA can be transferred to healthcare workers' gloves or hands from contaminated surfaces.[91-93] While some pathogens only survive a few days on inanimate surfaces, others, such as VRE, MRSA, Acinetobacter spp., and C. difficile can survive for months if not properly cleaned or disinfected.[94, 95] Furthermore, some pathogens, such as VRE or C. difficile, are more resistant to common disinfection methods than others. The link between environmental contamination and human infection has been difficult to establish firmly; however, various modelling studies, observational epidemiologic studies, interventional studies, as well as outbreak reports suggest this link exists.[7, 96, 97]

The optimal strategies for environmental disinfection in healthcare settings is unclear. Substantial evidence suggests that relying only on hand hygiene compliance among health workers is not an effective strategy. Two systematic reviews showed median rates of compliance with hand hygiene guidelines in hospital settings of 40% to 57%.[98, 99] Keyboards and computer devices pose additional challenges, including the difficulty of decontaminating their irregular surfaces and the potential for damage from cleaning products.[100] While multiple methods to decontaminate environmental surfaces generally have been developed, their effectiveness is unclear.[95, 97, 101, 102] Indeed, the CDC's Guidelines for Environmental Infection Control in Health-Care Facilities (updated in 2011) concluded that "More research is required to clarify the effectiveness and reliability of fogging, UV irradiation, and ozone mists to reduce norovirus environmental contamination," giving it a "No recommendation/unresolved issue" rating.[103] Results from our review suggest that little progress has been made in providing robust evidence for decontamination methods.

**Limitations of the Review**

As with any systematic review, our findings are limited by the quantity and quality of included studies. Heterogeneity across a number of areas limited our ability to conduct meta-analysis and/or draw inferences from our findings. This included heterogeneity in the swabbing and microbiological identification methods, study settings, study timeframes, sample sizes, and types of included devices. Outcome measures also varied; for example, some studies did not report a baseline contamination rate, and others did not specify the prevalence of specific pathogens identified. Fewer than half of the studies reported selection criteria which was pre-specified, clearly described, and implemented consistently. Only one study specifically sought to identify viruses (Norovirus).[61] Many potential pathogens were not specifically assessed in the included studies, and the data may represent an underestimate of contamination rates. Finally, nearly all included articles were conducted in hospital environments, and we have limited data on ambulatory or primary care settings.

**Implications for researchers, clinicians and policy makers**

Our findings indicate that the majority of keyboards and computer peripherals used in healthcare settings are contaminated with a range of microbes, including potential pathogens. Our findings do not allow us to draw firm conclusions about the relative impact of these 'reservoirs' of contamination as sources of transmission between patients and healthcare staff, nor their impact on HAI or nosocomial infections. However, given the central role that health IT plays in both inpatient and outpatient settings, it is possible that computer keyboards and peripherals may act as an important, yet largely unrecognized, common source of contamination and/or infection. Although evidence directly linking contaminated computer equipment and HAIs is scarce, evidence does demonstrate the effectiveness (albeit sometimes limited) of decontaminating potential fomites other than computer equipment as well as health workers' hands on reducing HAIs.[7, 96, 97, 104-106] Given this evidence, there is an urgent need to identify whether the same benefits apply to decontaminating computer equipment.

Our review highlights priorities for further research in this area. First, there is little data from primary care or outpatient settings on the extent of device contamination. Second, only a few studies tested iPads and other tablets, which is surprising given their growing use in healthcare, and potential ease of decontaminating their smooth surfaces. Third, more robust study designs are needed, and we encourage research using randomized controlled trials to test effectiveness of interventions. Finally, the relative impact of computer device contamination on colonization and infection of patients/healthcare workers is unclear from the current literature, thus it may be difficult to justify initiatives or interventions within healthcare systems that focus solely on computer devices.

In conclusion, computer keyboards and other peripheral computer devices in hospital settings are commonly contaminated, often with potentially pathogenic microbes. The evidence for the effectiveness of cleaning and decontamination methods to reduce the risk of HAI does not enable robust recommendations for the most effective tool(s). While the relative impact of these devices on HAI is unclear, evidence linking other similar fomites to HAI is sufficient to urge a closer evaluation of this relative impact and the effectiveness and feasibility of routine cleaning and decontamination methods.

**Figure Legend:**

**Figure 1:** Flow Diagram of Study Selection

**Funding:** No grants or contracts were received to conduct this study.

**Competing Interests**: None declared.

**Acknowledgements**: Many thanks to Sarah Safranik for assisting with the search strategy for the literature review.

**Contributions**: NI and MT designed the study methodology and conducted the literature search. NI extracted data from selected studies and MT checked extracted data for accuracy. NI and MT performed data analysis and developed the original draft of the article and contributed towards further drafts. Data interpretation and critical revision of the manuscript was done by BF, CL, and PV. All authors reviewed and approved the manuscript.

**Data sharing statement**: The complete data extraction form, quality assessment tables, and full search strategy can be made available upon request to the study authors.

## REFERENCES


1. Magill SS, Edwards JR, Bamberg W, et al. Multistate point-prevalence survey of health care-associated infections. *N Engl J Med* 2014;370(13):1198-208. doi: 10.1056/NEJMoa1306801 [published Online First: 2014/03/29]
2. Umscheid CA, Mitchell MD, Doshi JA, et al. Estimating the proportion of healthcare-associated infections that are reasonably preventable and the related mortality and costs. *Infection control and hospital epidemiology* 2011;32(2):101-14. doi: 10.1086/657912 [published Online First: 2011/04/05]
3. Rahmqvist M, Samuelsson A, Bastami S, et al. Direct health care costs and length of hospital stay related to health care-acquired infections in adult patients based on point prevalence measurements. *American journal of infection control* 2016;44(5):500-6. doi: 10.1016/j.ajic.2016.01.035 [published Online First: 2016/03/19]
4. Scott R. The direct medical costs of healthcare-associated infections in US hospitals and the benefits of prevention. Atlanta, GA: Centers for Disease Control and Prevention, 2009.
5. Weinstein RA. Epidemiology and control of nosocomial infections in adult intensive care units. *The American journal of medicine* 1991;91(3b):179s-84s. [published Online First: 1991/09/16]
6. de Oliveira AC, Damasceno QS. Surfaces of the hospital environment as possible deposits of resistant bacteria: A review. *Revista da Escola de Enfermagem* 2010;44(4):1118-23. doi: 10.1590/S0080-62342010000400038
7. Otter JA, Yezli S, French GL. The role played by contaminated surfaces in the transmission of nosocomial pathogens. *Infect Control Hosp Epidemiol* 2011;32(7):687-99. doi: 10.1086/660363 [published Online First: 2011/06/15]
8. Weber DJ, Anderson D, Rutala WA. The role of the surface environment in healthcare-associated infections. *Curr Opin Infect Dis* 2013;26(4):338-44. doi: 10.1097/QCO.0b013e3283630f04 [published Online First: 2013/06/08]
9. Dancer SJ. The role of environmental cleaning in the control of hospital-acquired infection. *The Journal of hospital infection* 2009;73(4):378-85. doi: 10.1016/j.jhin.2009.03.030 [published Online First: 2009/09/04]
10. Brady RR, Verran J, Damani NN, et al. Review of mobile communication devices as potential reservoirs of nosocomial pathogens. *J Hosp Infect* 2009;71(4):295-300. doi: 10.1016/j.jhin.2008.12.009 [published Online First: 2009/01/27]
11. Haun N, Hooper-Lane C, Safdar N. Healthcare Personnel Attire and Devices as Fomites: A Systematic Review. *Infection Control and Hospital Epidemiology* 2016;37(11):1367-73. doi: 10.1017/ice.2016.192
12. Moher D, Liberati A, Tetzlaff J, et al. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med* 2009;6(7):e1000097. doi: 10.1371/journal.pmed.1000097 [published Online First: 2009/07/22]
13. World Bank. World Bank Country and Lending Groups 2017 [Available from: https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups accessed 11/7/2017.
14. National Heart Lung Blood Institute. Assessing cardiovascular risk: systematic evidence review from the Risk Assessment Work Group 2013 [Available from:

https://www.nhlbi.nih.gov/sites/default/files/media/docs/risk-assessment.pdf accessed 7/20/2018.

15. Livshiz-Riven I, Borer A, Nativ R, et al. Relationship between shared patient care items and healthcare-associated infections: a systematic review. *International journal of nursing studies* 2015;52(1):380-92. doi: 10.1016/j.ijnurstu.2014.06.001 [published Online First: 2014/07/07]
16. Albrecht UV, Von Jan U, Sedlacek L, et al. Standardized, app-based disinfection of ipads in a clinical and nonclinical setting: Comparative analysis. *Journal of medical Internet research* 2013;15(8) doi: 10.2196/jmir.2643
17. Al-Hamad A, Maxwell S. How clean is clean? Proposed methods for hospital cleaning assessment. *Journal of Hospital Infection* 2008;70(4):328-34. doi: 10.1016/j.jhin.2008.08.006
18. Ali S, Muzslay M, Wilson P. A Novel Quantitative Sampling Technique for Detection and Monitoring of Clostridium difficile Contamination in the Clinical Environment. *Journal of clinical microbiology* 2015;53(8):2570-4. doi: 10.1128/jcm.00376-15 [published Online First: 2015/06/05]
19. Anastasiades P, Pratt TL, Rousseau LH, et al. Staphylococcus aureus on computer mice and keyboards in intensive care units of the Universitas Academic Hospital, Bloemfontein, and ICU staff's knowledge of its hazards and cleaning practices. *Southern African Journal of Epidemiology and Infection* 2009;24(2):22-26.
20. Bures S, Fishbain JT, Uyehara CF, et al. Computer keyboards and faucet handles as reservoirs of nosocomial pathogens in the intensive care unit. *American journal of infection control* 2000;28(6):465-71. doi: 10.1067/mic.2000.107267 [published Online First: 2000/12/15]
21. Cataño JC, Echeverri LM, Szela C. Bacterial contamination of clothes and environmental items in a third-level hospital in Colombia. *Interdisciplinary Perspectives on Infectious Diseases* 2012;2012 doi: 10.1155/2012/507640
22. Choi ES, Choi JH, Lee JM, et al. Is the environment of the endoscopy unit a reservoir of pathogens? *Intestinal research* 2014;12(4):306-12. doi: 10.5217/ir.2014.12.4.306 [published Online First: 2014/11/07]
23. Ciragil P, Gul M, Aral M. Bacterial contamination of computers and telephones in a university hospital in Turkey. The Journal of hospital infection. England2006:247-8.
24. Codish S, Toledano R, Novack V, et al. Effectiveness of stringent decontamination of computer input devices in the era of electronic medical records and bedside computing: a randomized controlled trial. *American journal of infection control* 2015;43(6):644-6. doi: 10.1016/j.ajic.2014.09.011 [published Online First: 2014/12/03]
25. Cordeiro ALAO, Oliveira MMC, Fernandes JD, et al. Equipment contamination in an intensive care unit. *ACTA Paulista de Enfermagem* 2015;28(2):160-65. doi: 10.1590/1982-0194201500027
26. Dancer SJ, White L, Robertson C. Monitoring environmental cleanliness on two surgical wards. *International journal of environmental health research* 2008;18(5):357-64. doi: 10.1080/09603120802102465 [published Online First: 2008/09/30]
27. Dancer SJ, White LF, Lamb J, et al. Measuring the effect of enhanced cleaning in a UK hospital: a prospective cross-over study. *BMC medicine* 2009;7(1):28. doi: 10.1186/1741-7015-7-28
28. De Grood J, Ward L, Harman S, et al. A cross-sectional point prevalence multi-hospital survey of health care associated pathogen contamination of computer keyboards. *Canadian Journal of Infectious Diseases and Medical Microbiology* 2012;23:13B.
29. Devine J, Cooke RP, Wright EP. Is methicillin-resistant Staphylococcus aureus (MRSA) contamination of ward-based computer terminals a surrogate marker for nosocomial MRSA transmission and handwashing compliance? *The Journal of hospital infection* 2001;48(1):72-5. doi: 10.1053/jhin.2001.0955 [published Online First: 2001/05/19]

30. Dumford DM, 3rd, Nerandzic MM, Eckstein BC, et al. What is on that keyboard? Detecting hidden environmental reservoirs of Clostridium difficile during an outbreak associated with North American pulsed-field gel electrophoresis type 1 strains. *American journal of infection control* 2009;37(1):15-9. doi: 10.1016/j.ajic.2008.07.009 [published Online First: 2009/01/28]
31. Duszak Jr R, Lanier B, Tubbs JA, et al. Bacterial contamination of radiologist workstations: Results of a pilot study. *Journal of the American College of Radiology* 2014;11(2):176-79. doi: 10.1016/j.jacr.2013.05.017
32. Engelhart S, Fischnaller E, Simon A, et al. Microbial contamination of computer user interfaces (keyboard, mouse) in a tertiary care centre under conditions of practice. *Hygiene + Medizin* 2008;33(12):504-07.
33. Faires MC, Pearl DL, Ciccotelli WA, et al. A prospective study to examine the epidemiology of methicillin-resistant Staphylococcus aureus and Clostridium difficile contamination in the general environment of three community hospitals in southern Ontario, Canada. *BMC infectious diseases* 2012;12:290. doi: 10.1186/1471-2334-12-290 [published Online First: 2012/11/10]
34. Faires MC, Pearl DL, Berke O, et al. The identification and epidemiology of meticillin-resistant Staphylococcus aureus and Clostridium difficile in patient rooms and the ward environment. *BMC infectious diseases* 2013;13:342. doi: 10.1186/1471-2334-13-342 [published Online First: 2013/07/26]
35. Fellowes C, Kerstein R, Clark J, et al. MRSA on tourniquets and keyboards. The Journal of hospital infection. England2006:86-8.
36. Farias PG, Gama F, Reis D, et al. Hospital microbial surface colonization revealed during monitoring of Klebsiella spp., Pseudomonas aeruginosa, and non-tuberculous mycobacteria. *Antonie van Leeuwenhoek* 2017;110(7):863-76. doi: 10.1007/s10482-017-0857-z [published Online First: 2017/03/25]
37. Fukada T, Iwakiri H, Ozaki M. Anaesthetists' role in computer keyboard contamination in an operating room. *The Journal of hospital infection* 2008;70(2):148-53. doi: 10.1016/j.jhin.2008.05.023 [published Online First: 2008/08/15]
38. Gerba CP, Wuollet AL, Raisanen P, et al. Bacterial contamination of computer touch screens. *American journal of infection control* 2016;44(3):358-60. doi: 10.1016/j.ajic.2015.10.013
39. Gostine A, Gostine D, Donohue C, et al. Evaluating the effectiveness of ultraviolet-C lamps for reducing keyboard contamination in the intensive care unit: A longitudinal analysis. *American journal of infection control* 2016;44(10):1089-94. doi: 10.1016/j.ajic.2016.06.012 [published Online First: 2016/08/16]
40. Grabsch EA, Mahony AA, Cameron DRM, et al. Significant reduction in vancomycin-resistant enterococcus colonization and bacteraemia after introduction of a bleach-based cleaning–disinfection programme. *Journal of Hospital Infection* 2012;82(4):234-42. doi: http://dx.doi.org/10.1016/j.jhin.2012.08.010
41. Gray J, Mc Nicholl B, Webb H, et al. Mice in the emergency department: Vector for infection or technological aid? *European Journal of Emergency Medicine* 2007;14(3):160-62. doi: 10.1097/MEJ.0b013e3280bef922
42. Hardy K, Abbott G, Bashford S, et al. Can measuring environmental cleanliness using ATP aid in the monitoring of wards with periods of increased incidence of Clostridium difficile? *J Infect Prev* 2014;15(1):31-35. doi: 10.1177/1757177413501568 [published Online First: 2014/01/01]
43. Hartmann B, Benson M, Junger A, et al. Computer keyboard and mouse as a reservoir of pathogens in an intensive care unit. *Journal of clinical monitoring and computing* 2004;18(1):7-12. doi: 10.1023/B:JOCM.0000025279.27084.39
44. Hassan RA, Rahman Bacterial contamination of computer keyboards and mouse. *Tikri, Jourual of Pure Science* 2014;19(5)

45. Hirsch EB, Raux BR, Lancaster JW, et al. Surface microbiology of the iPad tablet computer and the potential to serve as a fomite in both inpatient practice settings as well as outside of the hospital environment. *PLoS One* 2014;9(10):e111250. doi: 10.1371/journal.pone.0111250 [published Online First: 2014/11/02]
46. Hong D, Park S, Lee K, et al. Bacterial contamination of computer and hand hygiene compliance in the emergency department. *Hong Kong Journal of Emergency Medicine* 2012;19(6):387.
47. Jones R, Hutton A, Mariyaselvam M, et al. Keyboard cleanliness: A controlled study of the residual effect of chlorhexidine gluconate. *American journal of infection control* 2015;43(3):289-91. doi: 10.1016/j.ajic.2014.12.002
48. Jungnickel T, Von Jan U, Graf K, et al. Bugs! iPad-hygiene in healthcare. *Biomedizinische Technik* 2014;59:S1257-S60. doi: 10.1515/bmt-2014-5016
49. Karbasizade V, Sichani M, Parsafar S. Bacterial contamination of computer keyboards in hospitals in Isfahan in Iran. *International Journal of Biosciences (IJB)* 2014;4(1):320-24.
50. Keerasuntonpong A, Kesornsuk S, Trakulsomboon S, et al. Colonization of Nosocomial Pathogens on Computer Keyboards in Patient Care Areas. *Siriraj Medical Journal* 2017;57(9):380-81.
51. Khan A, Rao A, Reyes-Sacin C, et al. Use of portable electronic devices in a hospital setting and their potential for bacterial colonization. *American journal of infection control* 2015;43(3):286-8. doi: 10.1016/j.ajic.2014.11.013 [published Online First: 2015/01/06]
52. Kiedrowski LM, Perisetti A, Loock MH, et al. Disinfection of iPad to reduce contamination with Clostridium difficile and methicillin-resistant Staphylococcus aureus. *American journal of infection control* 2013;41(11):1136-7. doi: 10.1016/j.ajic.2013.01.030 [published Online First: 2013/05/11]
53. Link T, Kleiner C, Mancuso MP, et al. Determining high touch areas in the operating room with levels of contamination. *American journal of infection control* 2016;44(11):1350-55. doi: 10.1016/j.ajic.2016.03.013 [published Online First: 2016/11/05]
54. Lu PL, Siu LK, Chen TC, et al. Methicillin-resistant Staphylococcus aureus and Acinetobacter baumannii on computer interface surfaces of hospital wards and association with clinical isolates. *BMC infectious diseases* 2009;9:164. doi: 10.1186/1471-2334-9-164
55. Malta CP, Damasceno NN, Ribeiro RA, et al. Microbiological contamination in digital radiography: evaluation at the radiology clinic of an educational institution. *Acta odontologica latinoamericana : AOL* 2016;29(3):239-47. [published Online First: 2017/04/07]
56. Man GS, Olapoju M, Chadwick MV, et al. Bacterial contamination of ward-based computer terminals. The Journal of hospital infection. England2002:314-5.
57. Martin ET, Qin X, Baden H, et al. Randomized double-blind crossover trial of ultraviolet light-sanitized keyboards in a pediatric hospital. *American journal of infection control* 2011;39(5):433-35. doi: 10.1016/j.ajic.2010.10.016
58. Messina G, Ceriale E, Burgassi S, et al. Impact of a disinfecting technique on microbial contamination of computer keyboards and telephone handsets. *2* 2013 doi: http://www.sciedupress.com/journal/index.php/jha/article/view/2530
59. Messina G, Ceriale E, Lenzi D, et al. Environmental contaminants in hospital settings and progress in disinfecting techniques. *BioMed research international* 2013;2013:429780. doi: 10.1155/2013/429780 [published Online First: 2013/11/29]
60. Moore G, Muzslay M, Wilson AP. The type, level, and distribution of microorganisms within the ward environment: a zonal analysis of an intensive care unit and a gastrointestinal surgical ward. *Infection control and hospital epidemiology* 2013;34(5):500-6. doi: 10.1086/670219 [published Online First: 2013/04/11]

61. Morter S, Bennet G, Fish J, et al. Norovirus in the hospital setting: virus introduction and spread within the hospital environment. *The Journal of hospital infection* 2011;77(2):106-12. doi: 10.1016/j.jhin.2010.09.035 [published Online First: 2010/12/21]
62. Motta RH, Groppo FC, Bergamaschi Cde C, et al. Isolation and antimicrobial resistance of Staphylococcus aureus isolates in a dental clinic environment. *Infection control and hospital epidemiology* 2007;28(2):185-90. doi: 10.1086/510867 [published Online First: 2007/02/01]
63. Neely AN, Maley MP, Warden GD. Computer keyboards as reservoirs for Acinetobacter baumannii in a burn hospital. Clinical infectious diseases : an official publication of the Infectious Diseases Society of America. United States1999:1358-60.
64. Oguzkaya-Artan M, Baykan Z, Artan C, et al. Prevalence and risk factors for methicillin resistant Staphylococcus aureus carriage among emergency department workers and bacterial contamination on touch surfaces in Erciyes University Hospital, Kayseri, Turkey. *Afr Health Sci* 2015;15(4):1289-94. doi: 10.4314/ahs.v15i4.31 [published Online First: 2016/03/10]
65. Oie S, Yanagi C, Matsui H, et al. Contamination of environmental surfaces by Staphylococcus aureus in a dermatological ward and its preventive measures. *Biological and Pharmaceutical Bulletin* 2005;28(1):120-23. doi: 10.1248/bpb.28.120
66. Otter JA, Passaretti CL, French GL, et al. Low frequency of environmental contamination with methicillin-resistant Staphylococcus aureus in an inner city emergency department and a human immunodeficiency virus outpatient clinic. *American journal of infection control* 2011;39(2):151-3. doi: 10.1016/j.ajic.2010.05.022 [published Online First: 2010/10/05]
67. Patel S, Porter K, Sammons RL. Are computer keyboards a cross-infection risk in a dental clinic? *Journal of Infection Prevention* 2010;11(6):206-11. doi: 10.1177/1757177410384892
68. Phumisantiphong U, Diraphat P, Utrarachkij F, et al. Clonal spread of carbapenem resistant Acinetobacter baumannii in the patients and their environment at BMA Medical College and Vajira Hospital. *Journal of the Medical Association of Thailand = Chotmaihet thangphaet* 2009;92 Suppl 7:S173-80. [published Online First: 2010/03/18]
69. Pugliese A, Garcia AJ, Dobson W, et al. The prevalence of bacterial contamination of standard keyboards in an urban ED. *American Journal of Emergency Medicine* 2011;29(8):954-55. doi: 10.1016/j.ajem.2011.04.024
70. Rastogi S, Shah R, Perlman J, et al. Pattern of bacterial colonization in a new neonatal intensive care unit and its association with infections in infants. *American journal of infection control* 2012;40(6):512-5. doi: 10.1016/j.ajic.2012.02.016 [published Online First: 2012/08/03]
71. Reem RE, Van Balen J, Hoet AE, et al. Screening and characterization of Staphylococcus aureus from ophthalmology clinic surfaces: a proposed surveillance tool. *American journal of ophthalmology* 2014;157(4):781-87.e2. doi: 10.1016/j.ajo.2014.01.008 [published Online First: 2014/01/15]
72. Richard RD, Bowen TR. What Orthopaedic Operating Room Surfaces Are Contaminated With Bioburden? A Study Using the ATP Bioluminescence Assay. *Clin Orthop Relat Res* 2017;475(7):1819-24. doi: 10.1007/s11999-016-5221-5 [published Online First: 2017/01/05]
73. Rutala WA, White MS, Gergen MF, et al. Bacterial contamination of keyboards: efficacy and functional impact of disinfectants. *Infection control and hospital epidemiology* 2006;27(4):372-7. doi: 10.1086/503340 [published Online First: 2006/04/20]
74. Saito Y, Yasuhara H, Murakoshi S, et al. Time-dependent influence on assessment of contaminated environmental surfaces in operating rooms. *American journal of infection control* 2015;43(9):951-55. doi: 10.1016/j.ajic.2015.04.196
75. Schultz M, Gill J, Zubairi S, et al. Bacterial contamination of computer keyboards in a teaching hospital. *Infection control and hospital epidemiology* 2003;24(4):302-3. doi: 10.1086/502200 [published Online First: 2003/05/03]

76. Senok A, Garaween G, Raji A, et al. Genetic relatedness of clinical and environmental Acinetobacter baumanii isolates from an intensive care unit outbreak. *Journal of infection in developing countries* 2015;9(6):665-9. doi: 10.3855/jidc.6726 [published Online First: 2015/07/06]
77. Shaikh AA, Ely D, Cadnum JL, et al. Evaluation of a low-intensity ultraviolet-C radiation device for decontamination of computer keyboards. *American journal of infection control* 2016;44(6):705-7. doi: 10.1016/j.ajic.2015.11.025 [published Online First: 2016/01/20]
78. Smith SJ, Knouse MC, Wasser T. Prevalence of bacterial pathogens on physician handheld computers. *Journal of Clinical Outcomes Management* 2006;13(4):223-26.
79. Stambaugh RV, Elson L. Contaminated surfaces. *Dimensions of Dental Hygiene* 2009;7(6):(5p).
80. Sweeney CP, Dancer SJ. Can hospital computers be disinfected using a hand-held UV light source? The Journal of hospital infection. England2009:92-4.
81. Sykes A, Appleby M, Perry J, et al. An investigation of the microbiological contamination of ultrasound equipment. *British Journal of Infection Control* 2006;7(4):16-20. doi: 10.1177/14690446060070040501
82. Tan TY, Tan JS, Tay H, et al. Multidrug-resistant organisms in a routine ward environment: differential propensity for environmental dissemination and implications for infection control. *J Med Microbiol* 2013;62(Pt 5):766-72. doi: 10.1099/jmm.0.052860-0 [published Online First: 2013/02/09]
83. Trochesset DA, Walker SG. Isolation of Staphylococcus aureus from environmental surfaces in an academic dental clinic. *Journal of the American Dental Association (1939)* 2012;143(2):164-9. [published Online First: 2012/02/03]
84. Waghorn DJ, Wan WY, Greaves C, et al. Contamination of computer keyboards in clinical areas: potential reservoir for nosocomial spread of organisms. *British Journal of Infection Control* 2005;6(3):(3p).
85. Westerway SC, Basseal JM, Brockway A, et al. Potential Infection Control Risks Associated with Ultrasound Equipment - A Bacterial Perspective. *Ultrasound in medicine & biology* 2017;43(2):421-26. doi: 10.1016/j.ultrasmedbio.2016.09.004 [published Online First: 2017/03/28]
86. Wilson AP, Hayman S, Folan P, et al. Computer keyboards and the spread of MRSA. The Journal of hospital infection. England2006:390-2.
87. Wilson APR, Ostro P, Magnussen M, et al. Laboratory and in-use assessment of methicillin-resistant Staphylococcus aureus contamination of ergonomic computer keyboards for ward use. *American journal of infection control* 2008;36(10):e19-e25. doi: 10.1016/j.ajic.2008.09.001
88. Wilson AP, Smyth D, Moore G, et al. The impact of enhanced cleaning within the intensive care unit on contamination of the near-patient environment with hospital pathogens: a randomized crossover study in critical care units in two hospitals. *Critical care medicine* 2011;39(4):651-8. doi: 10.1097/CCM.0b013e318206bc66 [published Online First: 2011/01/19]
89. Xu H, Chen B, Ni X, et al. Computer keyboard and mouse: An intervention study on methicillin-resistant staphylococcus aureus decontamination in 4 intensive care units. *Journal of critical care* 2017;37:266-67. doi: 10.1016/j.jcrc.2016.09.021
90. Yun HC, Kreft RE, Castillo MA, et al. Comparison of PCR/electron spray ionization-time-of-flight-mass spectrometry versus traditional clinical microbiology for active surveillance of organisms contaminating high-use surfaces in a burn intensive care unit, an orthopedic ward and healthcare workers. *BMC infectious diseases* 2012;12:252. doi: 10.1186/1471-2334-12-252 [published Online First: 2012/10/12]
91. Rusin P, Maxwell S, Gerba C. Comparative surface-to-hand and fingertip-to-mouth transfer efficiency of gram-positive bacteria, gram-negative bacteria, and phage. *Journal of applied microbiology* 2002;93(4):585-92. [published Online First: 2002/09/18]

92. Stiefel U, Cadnum JL, Eckstein BC, et al. Contamination of hands with methicillin-resistant Staphylococcus aureus after contact with environmental surfaces and after contact with the skin of colonized patients. *Infection control and hospital epidemiology* 2011;32(2):185-7. doi: 10.1086/657944 [published Online First: 2011/04/05]
93. Boyce JM, Potter-Bynoe G, Chenevert C, et al. Environmental contamination due to methicillin-resistant Staphylococcus aureus: possible infection control implications. *Infection control and hospital epidemiology* 1997;18(9):622-7. [published Online First: 1997/10/06]
94. Kramer A, Schwebke I, Kampf G. How long do nosocomial pathogens persist on inanimate surfaces? A systematic review. *BMC infectious diseases* 2006;6:130. doi: 10.1186/1471-2334-6-130 [published Online First: 2006/08/18]
95. Dancer SJ. Controlling Hospital-Acquired Infection: Focus on the Role of the Environment and New Technologies for Decontamination. *Clin Microbiol Rev* 2014;27(4):665-90. doi: 10.1128/cmr.00020-14
96. Otter JA, Yezli S, Salkeld JA, et al. Evidence that contaminated surfaces contribute to the transmission of hospital pathogens and an overview of strategies to address contaminated surfaces in hospital settings. *American journal of infection control* 2013;41(5 Suppl):S6-11. doi: 10.1016/j.ajic.2012.12.004 [published Online First: 2013/05/03]
97. Donskey CJ. Does improving surface cleaning and disinfection reduce health care-associated infections? *American journal of infection control* 2013;41(5 Suppl):S12-9. doi: 10.1016/j.ajic.2012.12.010 [published Online First: 2013/03/08]
98. Erasmus V, Daha TJ, Brug H, et al. Systematic review of studies on compliance with hand hygiene guidelines in hospital care. *Infection control and hospital epidemiology* 2010;31(3):283-94. doi: 10.1086/650451 [published Online First: 2010/01/22]
99. Kingston L, O'Connell NH, Dunne CP. Hand hygiene-related clinical trials reported since 2010: a systematic review. *The Journal of hospital infection* 2016;92(4):309-20. doi: 10.1016/j.jhin.2015.11.012 [published Online First: 2016/02/09]
100. Dettenkofer M, Block C. Hospital disinfection: efficacy and safety issues. *Curr Opin Infect Dis* 2005;18(4):320-5. [published Online First: 2005/06/30]
101. Rutala WA, Weber DJ. Are room decontamination units needed to prevent transmission of environmental pathogens? *Infection control and hospital epidemiology* 2011;32(8):743-7. doi: 10.1086/661226 [published Online First: 2011/07/20]
102. Boyce JM. Modern technologies for improving cleaning and disinfection of environmental surfaces in hospitals. *Antimicrob Resist Infect Control* 2016;5:10. doi: 10.1186/s13756-016-0111-x [published Online First: 2016/04/14]
103. Sehulster L, Chinn RY, Arduino M, et al. Guidelines for environmental infection control in health-care facilities. *Morbidity and mortality weekly report recommendations and reports RR* 2003;52(10)
104. Ejemot-Nwadiaro RI, Ehiri JE, Arikpo D, et al. Hand washing promotion for preventing diarrhoea. *The Cochrane database of systematic reviews* 2015(9):Cd004265. doi: 10.1002/14651858.CD004265.pub3 [published Online First: 2015/09/09]
105. Falagas ME, Thomaidis PC, Kotsantis IK, et al. Airborne hydrogen peroxide for disinfection of the hospital environment and infection control: a systematic review. *The Journal of hospital infection* 2011;78(3):171-7. doi: 10.1016/j.jhin.2010.12.006 [published Online First: 2011/03/12]
106. Murphy CR, Eells SJ, Quan V, et al. Methicillin-resistant Staphylococcus aureus burden in nursing homes associated with environmental contamination of common areas. *J Am Geriatr Soc* 2012;60(6):1012-8. doi: 10.1111/j.1532-5415.2012.03978.x [published Online First: 2012/06/08]

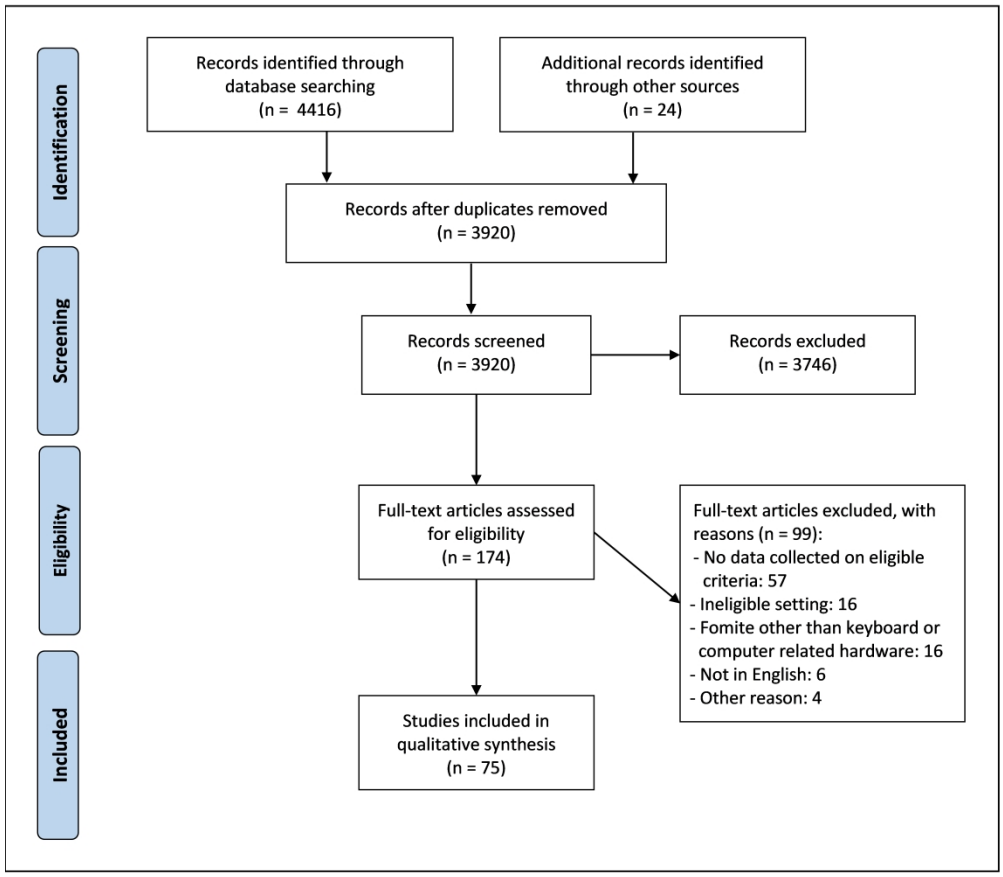


Figure 1 Flow Diagram of Study Selection

405x372mm (300 x 300 DPI)

# PRISMA 2009 Checklist

| Section/topic | # | Checklist item | Reported on page # |
|---|---|---|---|
| **TITLE** | | | |
| Title | 1 | Identify the report as a systematic review, meta-analysis, or both. | 1 |
| **ABSTRACT** | | | |
| Structured summary | 2 | Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number. | 2-3 |
| **INTRODUCTION** | | | |
| Rationale | 3 | Describe the rationale for the review in the context of what is already known. | 4 |
| Objectives | 4 | Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS). | 4-5 |
| **METHODS** | | | |
| Protocol and registration | 5 | Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number. | N/A |
| Eligibility criteria | 6 | Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale. | 5-6 |
| Information sources | 7 | Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched. | 5 |
| Search | 8 | Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated. | Suppl. File 2 |
| Study selection | 9 | State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis). | 5-6 |
| Data collection process | 10 | Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators. | 6-7 |
| Data items | 11 | List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made. | 6 |
| Risk of bias in individual studies | 12 | Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis. | 7 |
| Summary measures | 13 | State the principal summary measures (e.g., risk ratio, difference in means). | 7 |
| Synthesis of results | 14 | Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., $I^2$) for each meta-analysis. | 7 |

# PRISMA 2009 Checklist



| Section/topic | # | Checklist item | Reported on page # |
|---|---|---|---|
| Risk of bias across studies | 15 | Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies). | 7 |
| Additional analyses | 16 | Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified. | N/A |
| **RESULTS** | | | |
| Study selection | 17 | Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram. | 8 |
| Study characteristics | 18 | For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations. | Pp 8-9; Suppl. File 3 |
| Risk of bias within studies | 19 | Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12). | 15-16, Suppl. File 10 |
| Results of individual studies | 20 | For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot. | Pp 9-15; Table 1-2; Suppl. Files 4-9 |
| Synthesis of results | 21 | Present results of each meta-analysis done, including confidence intervals and measures of consistency. | N/A |
| Risk of bias across studies | 22 | Present results of any assessment of risk of bias across studies (see Item 15). | 15-16 |
| Additional analysis | 23 | Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]). | N/A |
| **DISCUSSION** | | | |
| Summary of evidence | 24 | Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers). | 16-19 |
| Limitations | 25 | Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias). | 18 |
| Conclusions | 26 | Provide a general interpretation of the results in the context of other evidence, and implications for future research. | 17, 18-19 |
| **FUNDING** | | | |
| Funding | 27 | Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review. | 20 |

*From:* Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097 

## Supplementary File 2: Example of search terms used

('cross infection'/exp OR 'cross infection':ti OR 'infection control'/exp OR 'disinfection'/exp OR disinfect*:ti OR 'medical device contamination'/exp OR 'disease transmission'/exp OR 'bacterial transmission'/exp OR 'disease carrier'/exp OR 'bacterial count'/exp OR 'microbiology'/exp OR 'antiinfective agent'/exp OR 'bacterial load'/exp OR 'bacterium identification'/exp OR 'bacterium contamination':ti OR 'microbial contamination':ti OR 'fungal contamination'/exp OR 'fungal detection'/exp OR contaminat*:ti OR decontaminat*:ti OR 'viral contamination':ti OR 'virus load'/exp OR 'ultraviolet radiation'/exp OR 'uv light':ab,ti OR 'ultraviolet light*':ab,ti OR 'uv lamp*':ab,ti OR 'ultraviolet lamp*':ab,ti OR 'waterproof keyboard*':ab,ti OR 'silicone cover*':ab,ti OR 'wipeable':ab,ti OR 'washable':ab,ti OR 'sanitiz*':ab,ti OR 'sanitis*':ab,ti OR 'steriliz*':ab,ti OR 'sterilis*':ab,ti OR 'swab*':ab,ti OR 'Vioguard' OR 'Seal Shield' OR 'Medigenic' OR 'Steridesign' OR 'SteriHood' OR 'Clinell' OR 'UV Angel' OR 'Esterline' OR 'hospital infection*':ab,ti OR 'HAI':ab,ti OR 'healthcare acquired infection*':ab,ti)

PLUS

('computer'/de OR 'computer mouse'/de OR 'keyboard'/de OR 'personal computer'/de OR 'personal digital assistant'/de OR keyboard*:ab,ti OR ipad:ab,ti OR ipads:ab,ti OR 'computer mouse':ab,ti OR 'computer mice':ab,ti OR 'mobile device*':ab,ti OR 'trackpad*':ab,ti OR 'mobile communication device*':ab,ti OR laptop:ab,ti OR laptops:ab,ti OR 'tablet computer*':ab,ti OR 'handheld computer*':ab,ti OR 'touch screen*':ab,ti OR 'touch-screen*':ab,ti)

## Supplementary File 3: Key characteristics of included studies

| AUTHOR, YEAR | SETTING | STUDY DESIGN | SAMPLE SIZE* | MICROBIOLOGICAL SAMPLING | OUTCOME MEASURE(S) | INTERVENTION DESCRIPTION (IF ANY) |
|---|---|---|---|---|---|---|
| **ALBRECHT 2013** | 10 clinical wards, Germany | Prospective comparative analysis | 10 iPads | Culture media with contact plates taken from 13 contact points on the iPad (front and back) | Total bacterial load | Isopropanol wipes using the 6-step disinfection process guided by the deBac-app. Devices in control arm cleaned with a cloth, without any liquid cleaning agents, as recommended in the iPad manufacturer instructions. |
| **AL-HAMAD 2008** | Nurse station areas in a hospital UK | Pre/Post | Unknown number of keyboards | Variety of hand-touch surfaces randomly sampled before and immediately after cleaning, prior to admission of a new patient. Surfaces in the common nurse station areas, where cleaning policy was not strictly followed, sampled randomly on two different occasions. Wards sampled 4 times: twice before cleaning and twice after. A subset of surfaces were sampled to determine the total aerobic count. | Total aerobic count (CFU) | |
| **ALI 2015** | Teaching hospital in UK | Cross Sectional | Unknown number of keyboards | Sampled by using either a contact plate or by wiping the entire test area (in a left-to-right motion, followed by wiping at 45° and 90° angles; the process was repeated 3 times) using a 25-cm2 sponge swab pre-moistened with neutralizing solution | Detection of C. diff | |
| **ANASTASIADES 2009** | ICUs at Academic Hospital South Africa | Repeated cross sectional, 2x | 14 keyboards and 14 mice | Moistened sterile swabs taken by student researchers trained by experienced medical technologist, taken at baseline and again 6 months later because initial sampling detected unexpectedly low S. aureus rates | Detection of CNS, Gram-positive bacilli, micrococci, fungi and S. aureus | |
| **BURES 2000** | ICU, USA | Repeated cross sectional, 2x/week for 2 months | 10 keyboards | Moistened swab from letter keys, space bar and enter key taken over 8 collection periods (2 nonconsecutive days of 2 nonconsecutive weeks for 2 months) | Total bacterial load | |
| **CATANO 2012** | Tertiary hospital, Colombia | Cross Sectional | 30 keyboards | Surfaces randomly sampled with moistened swabs during weekdays. | Total bacterial load | |

| AUTHOR, YEAR | SETTING | STUDY DESIGN | SAMPLE SIZE* | MICROBIOLOGICAL SAMPLING | OUTCOME MEASURE(S) | INTERVENTION DESCRIPTION (IF ANY) |
|---|---|---|---|---|---|---|
| **CHOI 2014** | Endoscopy rooms of 2 tertiary hospitals Korea | Cross sectional | Unknown number of keyboards | Moistened cotton tipped swabs were taken from all surfaces after endoscopy was performed, one time each in the morning and afternoon | Total bacterial load (CFU) | |
| **CIRAGIL 2006** | Patient and exam rooms, OR, offices, non-clinical areas, Turkey | Cross Sectional | 56 keyboards in clinical areas | Moistened swabs collected from entire surface of keyboard | Total bacterial load | |
| **CODISH 2015** | Internal medicine wards and ICU, Israel | Cluster RCT | 81 keyboards + 81 mice | Sampling done with Eswab. Culture specimens taken from keyboards and mice prior to the intervention and 2 weeks after intervention began. | Total bacterial load | MEDIWIPES (alcohol based) vs. TriGene (quaternary ammonium based). Each device decontaminated 3 times a day. |
| **CORDEIRO 2015** | ICU Brazil | Pre-post | 6 keyboards | Sterile swabs taken by the researchers, 2 swabs from each device (once before applying the cleaning/ disinfection product and another one right after the equipment was dried, without a pre-established waiting time) | Total bacterial load | Computer keyboards were cleaned on a daily basis with a brush for removing dust. |
| **DANCER 2008** | 2 acute surgical wards at a teaching hospital UK | Repeated cross sectional, 1x week for 6 months per ward | 2 keyboards, 1 per ward | Dip slides were used for sampling by an unspecified person. Screening was conducted in each ward for a 6 month period, first on ward B, then 6 months on ward A. Sampling done after routine cleaning and taken once weekly. | Hygienic failure was considered a site with ACC greater than 2.5 CFU/cm2 or any site demonstrating the presence of MSSA or MRSA | |
| **DANCER 2009** | 2 Surgical wards with endemic MRSA, UK | Prospective Cross-over | 2 keyboards | Dip slides used for sampling keyboards | Hygienic failure was considered a site with ACC greater than 2.5 cfu/cm2 or any site demonstrating the presence of MSSA or MRSA | Enhanced cleaning: additional cleaner added to ward and trained to clean hand-touch sites 1-3 times per day depending on location Monday to Friday. |

| AUTHOR, YEAR | SETTING | STUDY DESIGN | SAMPLE SIZE* | MICROBIOLOGICAL SAMPLING | OUTCOME MEASURE(S) | INTERVENTION DESCRIPTION (IF ANY) |
|---|---|---|---|---|---|---|
| **DE GROOD 2012** | Medical, surgical, ICU units in 4 urban hospitals, Canada | Cross sectional + nested Pre/Post | 240 keyboards | Conventional keyboards cultured 3 times using moistened sterile applicators: 1) in the morning pre cleaning, 2) approximately 2 hours following the initial swabs (after routine cleaning), and 3) post cleaning with a "CaviWipe". Later, 10 "Cleankeys" keyboards were placed on hospital ward in selected high usage areas of a Medical Centre and cultured pre-, after 2 hours, and post-cleaning using methods as above. | Total bacterial load | "CaviWipes" (a quaternary ammonium compound) with isopropanol) |
| **DEVINE 2001** | Nurse stations in 2 district hospitals' acute medical and surgical wards, UK | Cross Sectional | 25 terminals (keyboard, mouse, mouse pad) | Swabs taken from entire keyboards, mouse, and mouse mat by same individual | Detection of MRSA | |
| **DUMFORD 2009** | Patient rooms, physician and nurse work areas, portable equipment, 3 wards, USA | Pre/Post | 32 computers in initial survey, 25 computers and 1 mouse in follow up survey | Moistened swabs taken from entire keyboard surface | Detection of C. diff | Disinfection with bleach |
| **DUSZAK 2014** | outpatient radiology workstations in 2 hospitals, USA | Cross Sectional + Pre/Post at 2 hospitals | 7 mice | Samples taken using direct contact with sterile plates | Total bacterial load | "Chlorascrub" pads (chlorhexidine gluconate and isopropyl alcohol) |
| **ENGELHART 2008** | Non-clinical and clinical areas of a University Hospital, Germany | Cross Sectional | 77 computer terminals in clinical areas (keyboard, mouse) | Samples taken by direct contact using Rodac plates from the enter key, space bar, and mouse by trained investigator | Total bacterial load | |

| AUTHOR, YEAR | SETTING | STUDY DESIGN | SAMPLE SIZE* | MICROBIOLOGICAL SAMPLING | OUTCOME MEASURE(S) | INTERVENTION DESCRIPTION (IF ANY) |
|---|---|---|---|---|---|---|
| **FAIRES 2012** | 3 community hospitals, Canada | Repeated cross sectional at 4 time points | Unknown number of keyboards | Samples taken with dry electrostatic cloths, once per week for 4 consecutive weeks, prior to daily cleaning | Detection of MRSA or C. Diff | |
| **FAIRES 2013** | 2 Medical wards and 1 surgical ward Canada | Repeated cross sectional, 6 times over 15 weeks | Unknown number of keyboards | Sterile electrostatic cloths were used for sampling, done by the investigator. Half the surface with one cloth and the other half with another. Sampling was conducted once a week for 3 consecutive weeks during weeks 1–3 and weeks 13–15, prior to cleaning. | Detection of MRSA or C. Diff | |
| **FELLOWES 2006** | General clinical hospital areas, UK | Cross Sectional | 44 keyboards | Swabs taken from enter key and spacebar | Detection of MRSA or MSSA | |
| **FARIAS 2017** | Renal Transplant ward Portugal | Repeated cross sectional, over 3 months | 1 keyboard | Samples were always collected at the end of the morning and during lunch time, after the medical visits and treatments, collected over a 3 month period. Swabs were used to sample an area of 10x10 cm of each surface. | Total bacterial load | |
| **FUKADA 2008** | OR, ICU, consulting room, outpatient reception area, Japan | Pre/Post | Unknown number of keyboards | Moistened swabs taken from all keys before and after cleaning | Total bacterial load | Cotton cellulose sheet dampened with ethyl alcohol |
| **GERBA 2016** | Hospital, USA | Cross sectional | 17 computer touch screens | Samples taken from computer touch screens over course of one day using a sterile sponge stick | Coliform bacterial growth | |
| **GOSTINE 2016** | ICU, USA | Pre/Post with various exposure frequencies | 40 keyboards | Samples collected at 6AM, before cleaning. eSwab liquid based collection and transport system kit used for sampling | Total bacterial load | UV Angel Desktop lamps, set to 3-, 5-, 6-, and 10-minute cycle lengths |
| **GRABSCH 2012** | Hospital, Australia | Pre/Post | Unknown number of keyboards | Moistened swabs taken monthly during program periods B1 and B2 (not performed regularly during period A) | Detection of VRE | Hospital wide program including 'Bleach-Clean': replaced surface cleaners with sodium hypochlorite solution plus Chloradet detergent; install cleaner dispensing stations, employment of cleaning |

| AUTHOR, YEAR | SETTING | STUDY DESIGN | SAMPLE SIZE* | MICROBIOLOGICAL SAMPLING | OUTCOME MEASURE(S) | INTERVENTION DESCRIPTION (IF ANY) |
|---|---|---|---|---|---|---|
| | | | | | | supervisors and training program for cleaning staff, performance appraisals, modify protocols for managing VRE-colonized patients, thrice annual schedule of "super clean disinfection" |
| **GRAY 2007** | Emergency Northern Ireland | Repeated cross sectional, 3x over one year | 7 computer mice | Sampling was performed on three occasions over a 1 year period and performed unannounced by one of the authors. Moistened bacteriology swab used on the palm rest and left click button. A swab was also taken from the plastic edging surrounding the keyboard as a control | Total bacterial load | |
| **HARDY 2014** | All wards in 3 hospitals UK | Repeated cross sectional, over a 22 month period | Unknown number of keyboards and computers on wheels | Once a period of increased incidence of C. diff was identified, all wards had ATP sampling undertaken on a weekly basis in the afternoon by an infection control nurse. | RLU levels over 1,000 considered to be unacceptable (red code). A result between 500 and 1,000 RLU was given an intermediate rating or amber code | |
| **HARTMANN 2004** | ICU, Germany | Repeated cross sectional over 3 months | Unknown number of keyboards and mice | Keyboards and mice sampled with a moistened swab during 2 periods of 3 months each on 8 nonconsecutive days. | Potentially pathogenic microorganisms (2+ CFU) | |
| **HASSAN 2014** | Staff rooms, computer labs, internet centers in a teaching hospital, Iraq | Cross Sectional | 150 keyboards and 100 mice | Sterile swabs taken of keyboards and mice | Total bacterial load | |
| **HIRSCH 2014** | University department of pharmacy | Cross Sectional | 30 iPads | 5 swabs taken once (4 wet and 1 dry), 6 months following iPad distribution | Total bacterial load | |

| AUTHOR, YEAR | SETTING | STUDY DESIGN | SAMPLE SIZE* | MICROBIOLOGICAL SAMPLING | OUTCOME MEASURE(S) | INTERVENTION DESCRIPTION (IF ANY) |
|---|---|---|---|---|---|---|
| | practice, USA | | | | | |
| **HONG 2012** | Emergency dept of 3 teaching hospitals South Korea | Cross sectional | 112 computer items (56 keyboards and 56 mice) | A single sterile moistened swab was wiped over the keyboard and electronic mouse surfaces by one of the authors wearing sterile gloves. Keyboards were sampled by moving the sterile swab over the all keys over 60 seconds. The areas tested on each mouse were the palm rest, left and right click buttons of the mouse, and a standard 6 $cm^2$ area was swabbed. | Total bacterial load | |
| **JONES 2015** | ICU, UK | Controlled Trial | 8 keyboards for controlled study + 24 keyboards for intervention | Daily samples obtained using moistened swabs from entire keyboard and all keys at 4-6h and 24h of clinical use, daily for 16 days. | Total bacterial load | CHG spray (2% chlorhexidine gluconate-70% isopropyl alcohol) vs. TF spray (chlorine dioxide-based) |
| **JUNGNICKEL 2014** | Several clinical departments and wards at a Medical School, Germany | Pre/Post | 5 iPads | Sampling using contact plates done before and after disinfection intervention | Total bacterial load | Isopropanol wipes using the 6-step disinfection process guided by the deBac-app. |
| **KARBASIZADE 2014** | Medical wards of various hospitals Iran | Cross sectional | 65 keyboards | A sterile swab which had been dampened by Trypticase soy agar, was applied on the entire keyboard. | Total bacterial load | |
| **KEERASUNTO-NGPONG 207** | General medical wards, ICU Thailand | Cross sectional | 26 keyboards | A sterile cotton swab, moistened with sterile normal saline solution, was rolled over the F and J keys, the number 4 and 5 keys, and the enter key and space bar | Total bacterial load | |
| **KHAN 2015** | 2 large academic institution medical centers, USA | Cross Sectional | 106 portable electronic devices (93 were iPads/ tablet) | Moistened swabs taken of house officers' and attending physicians' carrying devices. Separate swabs were used for the screen, cover, and keyboard if applicable. | Total bacterial load | |
| **KIEDROWSKI 2013** | Hospital, USA | Cross Sectional | 20 iPads | iPad screens swabbed. | Detection of C.diff, MRSA | |

| AUTHOR, YEAR | SETTING | STUDY DESIGN | SAMPLE SIZE* | MICROBIOLOGICAL SAMPLING | OUTCOME MEASURE(S) | INTERVENTION DESCRIPTION (IF ANY) |
|---|---|---|---|---|---|---|
| **LINK 2016** | OR, USA | Cross sectional with control | Unknown number of keyboards and mice | Samples obtained over a 3 week period, pre- and post-procedure and before cleaning. Samples taken with a sponge stick. | Total bacterial load | |
| **LU 2009** | All ward stations of university hospital, Taiwan | Cross Sectional | 282 stations (keyboard and mouse) | Moistened swabs taken from keyboards and mice | S. aureus, Pseudomonas sp, and Acinetobacter sp | |
| **MALTA 2016** | Dental radiology clinic at public educational institution, Brazil | Repeated cross sectional at 2 time points | Unknown number of keyboard and mice on radiological equipment | Sterile moistened swab samples collected over 3 nonconsecutive random days at 2 different times: in the morning, before attending patients, and at end of day after appointment hours and before cleaning and disinfection procedures. | Total bacterial load | |
| **MAN 2002** | Nurse stations, patient bed bays in multiple wards, UK | Cross Sectional | 85 keyboards + 80 mice + 44 mouse pads | Sterile moist swabs taken of the entire surface of every key and crevice of each keyboard, mouse, and mouse pad | Total bacterial load | |
| **MARTIN 2011** | ICU and ER in pediatric hospital, USA | Randomized double blind cross-over trial | 72 terminals (keyboards/ mouse/pad): 24 Vioguard keyboards, 24 control keyboards, 24 existing keyboards | Moistened swabs taken from the mouse pad, mouse buttons, and the ''F,'' ''M,'' ''Enter,'' and ''Space'' keys, sampled with a single swab | Total bacterial load | Keyboards with "Vioguard" UV light irradiation with identical control keyboards not exposed to UV light irradiation. |
| **MESSINA 2013 (A)** | 4 different medical units, Italy | Pre/Post | 27 keyboards | A first swab taken from one half of the surfaces before cleaning with the putty and a second sample from other half of surfaces after cleaning. Sides were alternated. | Total bacteria count of: Staphylococcus spp, Pseudomonas spp, E. coli, total coliform bacteria, C.diff, Acinetobacter spp, | A putty cleaning compound (ethanol 29%) with malleable-elastic consistency, designed to adhere to surfaces, remove dirt and disinfect |

| AUTHOR, YEAR | SETTING | STUDY DESIGN | SAMPLE SIZE* | MICROBIOLOGICAL SAMPLING | OUTCOME MEASURE(S) | INTERVENTION DESCRIPTION (IF ANY) |
|---|---|---|---|---|---|---|
| **MESSINA 2013 (B)** | Various units within 3 hospitals, Italy | Pre/Post | 50 keyboards | A first swab taken from one half of each keyboard before cleaning, and a second sample from other half after cleaning. Samples obtained by swabbing almost all the keys and also going between/under the keys with cotton sterile pads. | Total bacterial load | A putty cleaning compound (ethanol 29%) with malleable-elastic consistency, designed to adhere to surfaces, removing dirt and disinfect |
| **MOORE 2013** | ICU and GI surgical wards, UK | Repeated cross sectional over 17 weeks | Unknown number of keyboards | Sampling conducted on variety of surfaces using direct contact methods (blood agar contact plates). 33 samples taken over 17 weeks. | Aerobic colony counts | |
| **MORTER 2011** | Ward rooms, UK | Cross sectional Post-intervention | 10 keyboards + 8 mice | All surfaces in rooms where NoV infected patients stayed were cleaned with Actichlor solution. Then, moistened swabs taken from variety of surfaces, including keyboards/mice. Two wards on which NoV was detected on environmental surfaces after cleaning were subjected to second clinical clean and tested again. | Detection of Norovirus | Actichlor plus solution |
| **MOTTA 2007** | Undergrad dental school clinic, Brazil | Repeated cross sectional at 1/mo over 1 year | 4 keyboards | 3 samples (moistened swabs) taken bimonthly during a 1 year period - before, during, and after clinical procedure hours. | Detection of S. aureus | |
| **NEELY 1999** | Burn Hospital, USA | Pre/Post | Unknown number of keyboards | Not specified | Detection of Acinetobacter species | Enhanced cleaning policy: All personnel required to wear gloves before using computer and removed before leaving the room. Also, housekeeping staff given a defined daily cleaning procedure for cleaning the plastic keyboard covers |
| **OGUZKAYA-ARTAN 2015** | ER, Turkey | Cross Sectional | 14 keyboards + 5 desktop surfaces | Swab samples taken from keyboards | Detection of S. aureus | |
| **OIE 2005** | Dermatology ward, Japan | Cross Sectional | 1 keyboard | Samples taken of entire surface of keyboards with moistened sterile gauze swab. For the items showing contamination by 100 CFU or more MRSA or MSSA in at least one of the repeated examinations, half the area of each | Detection of S. aureus | |

| AUTHOR, YEAR | SETTING | STUDY DESIGN | SAMPLE SIZE* | MICROBIOLOGICAL SAMPLING | OUTCOME MEASURE(S) | INTERVENTION DESCRIPTION (IF ANY) |
|---|---|---|---|---|---|---|
| | | | | surface was examined for S. aureus contamination. Subsequently, entire surface disinfected and the other half area was examined for contamination. | | |
| **OTTER 2011** | Hospital emergency department and an outpatient HIV clinic US | Cross sectional | Unknown number of keyboards | Cotton-tipped moistened sterile swabs used. Surfaces swabbed 100 $cm^2$ areas by standardized swabbing in two directions at right angles. | Detection of MRSA | |
| **PATEL 2010** | 2 student study areas and 2 patient clinics in a dental hospital, UK | Cross sectional + nested Pre/Post | 8 keyboards | Keyboards swabbed using swab moistened with sterile distilled water by a single investigator. Keyboards sampled 3 times each: by running the tip of the swab from left to right over the entire length covering the tops of all the keys and then turning the swab and returning over the same surface.<br>Later, 2 keyboards in clinical and study areas disinfected twice a day using isopropanol wipes. After 5 days, they were swabbed again. | Total bacterial load | 70% isopropanol wipes vs. Virkon (dipotassium peroxodisulphate) |
| **PHUMISANTIPHONG 2009** | Hospital patient rooms and nurse station, Thailand | Cross Sectional | 30 computer terminals (keyboards/ mice) | Not specified | Detection of CRAB | |
| **PUGLIESE 2011** | ER, USA | Cross Sectional | 72 keyboards | Keyboards sampled by moist swab, taken from all keys except the function keys | Total bacterial load | |
| **RASTOGI 2012** | NICU, USA | Repeated cross sectional, biweekly for 1 yr | 3 keyboards | Samples taken using moistened swabs biweekly for 1 year by a culture swab and transport company | Total bacterial load | |
| **REEM 2014** | Exam and imaging rooms, common areas in an ophthalmolo | Repeated cross sectional, quarterly for 1 year | 16 keyboards | Sampling conducted on quarterly basis for 1 year. Collected at the end of day, prior to daily cleaning by a trained personnel wearing clean clothing covers and gloves. (Unclear if keyboard sampling done using electrostatic cloth or moistened swabs.) | Detection of MRSA/MSSA isolates | |

| AUTHOR, YEAR | SETTING | STUDY DESIGN | SAMPLE SIZE* | MICROBIOLOGICAL SAMPLING | OUTCOME MEASURE(S) | INTERVENTION DESCRIPTION (IF ANY) |
|---|---|---|---|---|---|---|
| | gy clinic, USA | | | | | |
| **RICHARD 2017** | Orthopedic OR, USA | Cross Sectional | 6 keyboards | On a given day, surfaces in 6 different orthopedic surgery operating rooms tested before surgery with ATP bioluminescence swabs | Total bacterial load, measured in RLUs | |
| **RUTALA 2006** | Burn ICU, cardiothoracic ICU, nursing units, USA | Cross Sectional | 25 keyboards | Single sterile swab wiped over entire surface of keyboards | Total bacterial load | |
| **SAITO 2015** | Six ORs, Japan | Cross Sectional | 12 keyboards and 6 touch screens | Contamination assessed using an ATP test and bacterial culture using moistened swabs | mean ATP value (log10 RLU)<br>for microbial count: log10 CFU | |
| **SCHULTZ 2003** | VA hospital: areas close to patients in acute care, ambulatory care, and long term care, USA | Cross Sectional | 100 keyboards | During 4 week period, samples taken using moistened swabs from all over keyboard surfaces | Total bacterial load | |
| **SENOK 2015** | ICU nursing stations, Saudi Arabia | Cross Sectional | Unknown number of keyboards and mice | ATM moistened swabs taken of environmental surfaces during an outbreak of multi-drug resistant A. baumannii (MRAB) | Detection of A. baumannii isolates | |
| **SHAIKH 2016** | Unknown hospital setting, USA | Pre/Post with various exposure frequencies | 25 keyboards in current use but unclear setting | One half of the keyboard sampled with a moistened swab before use of the UV device, and the other half sampled after decontamination. | Total bacterial load | UV Angel system |
| **SMITH 2006** | Medical, surgical, family practice programs of tertiary hospital, USA | Pre/Post | 60 notebooks (keys and grips) | Samples taken over approximately 8 days over several-month period. Sampling done with moistened swab wiped over space key and enter key.<br>An identical protocol used for 17 devices looking specifically for C. difficile but did not test for spores. | Total bacterial load | Clorox disinfecting wipes |

| AUTHOR, YEAR | SETTING | STUDY DESIGN | SAMPLE SIZE* | MICROBIOLOGICAL SAMPLING | OUTCOME MEASURE(S) | INTERVENTION DESCRIPTION (IF ANY) |
|---|---|---|---|---|---|---|
| | | | | For general comparison, swabs were taken from 23 hospital hallway desktop computers on all patient care floors and units. Following the culture collection, medical residents were instructed to disinfect their notebooks 3 times per day with Clorox disinfecting wipes. Three days after the protocol was introduced, the devices were randomly swabbed again. | | |
| **STAMBAUGH 2009** | Dental office, USA | Pre/Post with stratified groups | 88 keyboards or mice | Keyboards/mouse devices, which had never been cleansed or disinfected, sampled with a single sterile moistened swab over the entire keyboard and mouse. Then, keyboards were divided in 3 groups and evaluated for contamination over a period of 4 months. | Detection of Multidrug-resistant organisms | Disinfectant wipes (ammonium chloride and isopropyl alcohol) |
| **SWEENEY 2009** | Various clinical wards, A&E, UK | Pre/Post | 68 computer terminals (keyboards/ mice) | Samples taken on different sides of keyboard and mouse using dip slides coated with nutrient and Baird parker agars. After sampling, keyboard/mouse exposed to UV device and resampled. | Total bacterial load | Astroplast Nano-UV disinfectant light scanner |
| **SYKES 2006** | Unknown clinical setting, UK | Repeated cross sectional over 3 months | 5 ultrasound machine keyboards | 5 machines sampled randomly on different days of the week and at different times over a period of 3 months (total of 15 times). Sampled using moistened swab by person wearing sterile gloves. | Total bacterial load | |
| **TAN 2013** | 2 open wards in a 800 bed acute care hospital, Singapore | Cross sectional | Unknown number of keyboards | Sampling carried out over a 2-month period. Neither cleaning nor ward staff were informed about the sampling, which was performed at random intervals (equally during morning and afternoon periods) during the routine working day by non-ward-based technologists. Keyboards were sampled by moving a sterile flocked nylon moistened swab over the letter keys. | Presence of MRSA, E. coli and K. pneumoniae resistant to third-generation cephalosporins, CRAB and VRE. | |
| **TROCHESSET 2012** | School of Dental Medicine US | Repeated cross sectional, 8 times over 62 weeks | Unknown number of keyboards and mice | Sampling conducted 8 times over a 62-week period (not clear if all surfaces were sampled all 8 times). Sampling dates were at least one month apart. Done between 1 p.m. and 2 p.m., when patient care was not being delivered, in-between patients. One researcher immersed | Detection of S. aureus | |

| AUTHOR, YEAR | SETTING | STUDY DESIGN | SAMPLE SIZE* | MICROBIOLOGICAL SAMPLING | OUTCOME MEASURE(S) | INTERVENTION DESCRIPTION (IF ANY) |
|---|---|---|---|---|---|---|
| | | | | sterile polyester fiber–tipped swabs in sterile saline for 1 second and sampled the surfaces by rubbing the moistened swab over the object for 10 seconds. | | |
| **WAGHORN 2005** | Various clinical wards, ICU, A&E, OPD, OR, UK | Cross Sectional | 48 keyboards | Moistened sterile swabs rubbed over each keyboard surface including any mice | Total bacterial load and degree of growth (including S. aureus, hemolytic streptococci, P. aeruginosa and C. diff) | |
| **WESTERWAY 2017** | Ultrasound units in a public hospital and private practice, Australia | Cross Sectional | 10 ultrasound keyboards | Keyboards sampled using sterilin transport swabs | Total bacterial load | |
| **WILSON 2006** | ICU, UK | Cross Sectional | 17 keyboards | 51 samples collected using contact plates. Keyboards sampled daily until patients left the bed space. | Total bacterial load | |
| **WILSON 2008** | ICU, UK | Controlled Trial | 32 keyboards | Sampling conducted on 10 days over a 2-week period (80 samples total) between 11am-12pm each day using contact plates. | Detection of S. aureus and Acinetobacter sp. | Comparison of 3 types of keyboards: Medigenic (gives alarm when cleaning is required), Anonymous brand, and standard keyboards |
| **WILSON 2011** | ICU at 2 teaching hospitals, UK | Prospective randomized cross-over | Unknown number of keyboards | Direct contact method was used using dip slides; performed 3 times daily (before cleaning, middle of day, after cleaning) on 3 days per week for 48 weeks | Total aerobic colony count | Enhanced cleaning: extra twice daily cleaning using cloths soaked in a copper-based biocidal formulation |
| **XU 2017** | Medical ICU and NICU, China | Pre/Post | Unknown number of keyboards and mice | Sampling was performed by infection control professionals at 10 AM every quarter. Mouse, 10 letter keys and 10 number keys were sampled using neutralizer moistened sterile swabs. | Detection of MRSA | Traditional cotton cloth and bucket system vs. disinfectant wipes |
| **YUN 2012** | Patient rooms in burn ICU | Cross sectional | Unknown number of | Two swabs (one for TCM and one for PCR/ESI-TOF-MS) were obtained using a standard rolling | Total bacterial load | |

| AUTHOR, YEAR | SETTING | STUDY DESIGN | SAMPLE SIZE* | MICROBIOLOGICAL SAMPLING | OUTCOME MEASURE(S) | INTERVENTION DESCRIPTION (IF ANY) |
|---|---|---|---|---|---|---|
| | and orthopedic ward USA | | keyboards and mice | technique from the keyboard and mouse in each of the 20 patient rooms, where available | | |

*Some studies with sample size "unknown number of keyboards" reported only number of samples taken, not total devices used.

Abbreviations: A. baumannii = Acinetobacter baumannii, ACC = Aerobic Colony Counts, A&E = Accident and Emergency Unit, ATM = Amies transport medium, ATP = Adenosine triphosphate, C. Diff = Clostridium difficile, CFU = Colony forming units, CNS = Coagulase-negative staphylococcus, CRAB = Carbapenem-resistant Acinetobacter baumannii, E. Coli = Escherichia coli, ER = Emergency room, GI = gastrointestinal, ICU = Intensive care unit, K. pneumonia = Klebsiella pneumonia, MRSA = Methicillin-resistant Staphylococcus aureus, MSSA = Methicillin-sensitive Staphylococcus aureus, NICU = Neonatal Intensive Care Unit, NoV = Norovirus, OR = Operating room, OPD = Outpatient Department, P. aeruginosa = Pseudomonas aeruginosa, RCT = Randomized Controlled Trial, RLU = Relative light units, S. aureus = Staphylococcus aureus, TCM = Traditional clinical microbiology, VRE = Vancomycin-resistant Enterococcus

## Supplementary File 4: Studies reporting overall contamination as colony forming units (CFU)

| AUTHOR, YEAR | SETTING | DEVICE AND NUMBER | CONTAMINATION MEASURED USING CFUs |
|---|---|---|---|
| **ALBRECHT 2013** | 10 clinical wards | 10 iPads | 1842 total CFU found overall iPads (162 median CFU per device) |
| **AL-HAMAD 2008** | Nurse station in hospital | Unknown number of keyboards | From nurse station areas without cleaning policy:<br>4 CFU/cm² (± SE: 2.75, 5.25) |
| **CHOI 2014** | Endoscopy rooms of 2 tertiary hospitals | Unknown number of keyboards and mice | Doctor's computer keyboard: 974 CFU<br>Nurse's computer mouse: 764 CFU<br>Doctor's computer mouse: 180 CFU<br>Endoscopy keyboard: 595 CFU (approx. from graph) |
| **FARIAS 2017** | Renal transplant ward in tertiary hospital | 1 keyboard | <20 CFU/100 cm² |
| **FUKADA 2008** | OR, ICU, consulting room and outpatient reception area | Unknown number of keyboards | Mean bacterial counts CFU/ml (SD):<br>OR: 333 (141)<br>ICU: 1015 (501)<br>Consulting room and reception area for outpatients: 1113 (1420) |
| **GERBA 2016** | Hospital | 17 computer touch screens | Average number of bacteria on touch screens was 2,257 CFUs (800-1,000/ cm²). |
| **JONES 2015** | ICU | 8 keyboards for controlled study + 24 keyboards for intervention | 57% keyboards had contamination of >500 CFU before cleaning |
| **JUNGNICKEL 2014** | Several clinical departments and wards at a Medical School | 5 iPads | 2,033 CFU in total (median: 416) counted on the 5 devices |
| **LINK 2016** | Operating room | Unknown number of keyboards and mice | Median CFU/cm² (min, max):<br>Keyboard: 0.47 (9.9, 61.67)<br>Mouse: 0.26 (0.0, 35.26) |
| **MALTA 2016** | Dental radiology clinic at a public educational institution | Unknown number of keyboard and mice on radiological equipment | Intraoral: (mean CFU before/after clinical use)<br>Cocci: mouse (.05/0) keyboard (0.1/0.01)<br>GNB: mouse (0/0), keyboard (0/0)<br>Fungi: mouse (5.9/0.05), keyboard (0.78/0.13)<br>Extraoral:<br>Cocci: mouse (0.03/0.1) keyboard (0.46/0.2)<br>GNB: mouse (0.01/0) keyboard (0.2/0.36)<br>Fungi: mouse (0.18/0.01) keyboard (0.36/0.16) |
| **MOTTA 2007** | Undergrad dental school clinic | 4 keyboards | Mean CFU ranged from 0.23 to 1.03 before, 2.26 to 2.64 during, and 0.66 to 1.46 after clinical procedures. |
| **WILSON 2008** | ICU | 32 keyboards | For Medigenic keyboards, baseline contamination rates ranged from 38-65 CFU, depending on the alarm interval set |

Abbreviations: CFU = Colony forming units, ICU = Intensive care unit, OR = Operating room, SD = Standard deviation

## Supplementary File 5: Studies reporting overall contamination using other quantitative methods

| AUTHOR YEAR | SETTING | DEVICE AND NUMBER | OUTCOME MEASURES | CONTAMINATION MEASURED USING OTHER QUANTITATIVE METHODS |
|---|---|---|---|---|
| **CATANO 2012** | Tertiary hospital | 30 keyboards | Total bacterial load | 39 isolations obtained from the 30 keyboards; 56.4% of isolations considered potentially clinically relevant |
| **DANCER 2008** | 2 acute surgical wards at a teaching hospital | 2 keyboards (52 total swabs) | Hygiene failure (a site with ACC > 2.5 CFU/cm2 or any site with the presence of MSSA or MRSA | 13/52 swabs |
| **HARDY 2014** | All wards in 3 hospitals | Unknown number of computer keyboards and COWs | Percentage of times each of the sites failed (>1,000 RLU) ATP monitoring | Computers on wheels: 33.1%<br>Keyboards: 34.7% |
| **HARTMANN 2004** | ICU | Unknown number of keyboards and mice | Potentially pathogenic microorganisms (2+ CFU) | Keyboards: 15/238 (6.3%) of samples<br>Mice: 13/238 (5.5%) of samples |
| **MAN 2002** | Nurse stations, patient bed bays in a number of different wards | 85 computer keyboards + 80 mice + 44 mouse pads | Total bacterial load | 40/85 (47%) keyboards, 36/80 (45%) mice, and 15/44 (34%) mouse pads yielded multiple bacterial species |
| **MOORE 2013** | ICU and GI surgical wards | Unclear # of keyboards | Aerobic colony counts | GI ward: 8/66 (12%) keyboards contaminated at levels > 100 CFU/ 25 $cm^2$ on at least 1 occasion<br>Data for ICU not reported |
| **PUGLIESE 2011** | Emergency dept | 72 keyboards | Total bacterial load | 10 (13.8%) colonized with 9 different identified bacteria |
| **RASTOGI 2012** | NICU | 3 keyboards | Total bacterial load | 5 positive cultures obtained from keyboards |
| **SAITO 2015** | Six ORs | 12 keyboards and 6 touch screens | mean ATP value (log10 RLU) | Keyboards for nurses: 2.8 +/- 0.3<br>Keyboards for anesthesiologists: 2.8 +/- 0.3<br>Touch screens for anesthesiologists: 2.0 +/- 0.3 |
| **SYKES 2006** | Unknown clinical setting, UK | 5 ultrasound machine keyboards | Total bacterial load | Pathogens identified: Acinetobacter (2 keyboards), Acinetobacter lwoffii, Enterococcus faecium, Enterococcus faecalis, Pseudomonas putida, S. aureus (fully sensitive) |

Abbreviations: ACC = Aerobic Colony Counts, ATP = Adenosine triphosphate, CFU = Colony forming units, COWs = computers on wheels, GI = gastrointestinal, ICU = Intensive care unit, NICU = Neonatal Intensive Care Unit, OR = Operating room, RLU = Relative light units, S. aureus = Staphylococcus aureus

## Supplementary File 6: Studies reporting overall contamination only of a single or specific pathogens

| AUTHOR YEAR | SETTING | DEVICE AND NUMBER | OUTCOME MEASURES | CONTAMINATION MEASURED |
|---|---|---|---|---|
| **ALI 2015** | Teaching hospital | Unknown number of keyboards | Detection of C. diff | C. diff detected using sponge swab: 3/15 (20%) |
| **ANASTAS-IADES 2009** | ICUs at Academic Hospital | 14 keyboards and 14 mice | Detection of CNS, Gram-positive bacilli, micrococci, fungi and S. aureus | First round of screening: (Keyboards\|Mice):<br>S. aureus: 0/14 (0%) \| 1/14 (7.1%)<br>CNS: 14/14 (100%) \| 14/14 (100%)<br>Others (estimated colony counts):<br>Gram positive bacilli: 193 \| 28<br>Micrococcus: 2 \| 3<br>Fungi: 14 \| 0 |
| **CIRAGIL 2006** | Patient and exam rooms, OR, offices, non-clinical areas | 56 keyboards in clinical areas | Total bacterial load | MSSE: 23/56 (41.1%)<br>Bacillus: 21/56 (37.5%)<br>Enterococcus: 7/56 (12.5%)<br>MSSA: 1/56 (1.8%)<br>Enterobacter: 6/56 (10.7%)<br>Sphingomonas paucimobilis: 1 (2%)<br>Streptococcus: 1/56 (1.8%)<br>E. coli: 4/56 (7.1%)<br>Corynebacterium: 1/56 (1.8%)<br>Klebsiella ozanae: 1/56 (1.8%) |
| **DEVINE 2001** | Nurse stations in 2 district hospital acute medical and surgical wards | 25 terminals (keyboard, mouse, mouse pad) | Detection of MRSA | MRSA: 24% total<br>(42% in hospital A and 8% in hospital B) |
| **DUMFORD 2009** | Patient rooms, physician and nurse work areas, portable equipment, 3 wards | 32 computers in initial survey, 25 computers and 1 mouse in follow up survey | Detection of C. diff | C. diff: 9/32 (28%) |
| **ENGELHART 2008** | Non-clinical and clinical areas of a University Hospital | 77 computer terminals in clinical areas (keyboard, mouse) | Total bacterial load | S. aureus: 10/77 (13%)<br>Viridans streptococci (Gram-pos bacteria): 8/77 (10.4%)<br>Enterococci: 7/77 (9.1%)<br>Gram negative: 13/77 (16.9%)<br>Molds: 17/77 (22.1%) |
| **FAIRES 2012** | 3 community hospitals | Unknown number of keyboards | Detection of MRSA or C. Diff | At each hospital:<br>MRSA: 0/8 (0%) samples, 2/29 (6.9%) samples, 2/25 (8.0%) samples<br>C. diff: 0/9 (0%), 0/29 (0%), 3/25 (12%) |
| **FAIRES 2013** | 2 Medical wards and 1 surgical ward | Unknown number of keyboards | Detection of MRSA or C. Diff | MRSA: 1/55 samples (1.8%)<br>C. diff: 3/55 (5.5%) |

| | | | | |
|---|---|---|---|---|
| **FELLOWES 2006** | General clinical hospital areas | 44 keyboards | Detection of MRSA or MSSA | MSSA: 9/44 (20%)<br>MRSA: 4/44 (9%) |
| **GRABSCH 2012** | Hospital | Unknown number of keyboards | Detection of VRE | VRE: 1/9 (11%) swabs |
| **HIRSCH 2014** | University department of pharmacy practice | 30 iPads | Total bacterial load | S. aureus: 22/30 (73.3%)<br>MRSA: 15/30 (50%)<br>Enterococci: 30/30 (100%)<br>VRE: 1/30 (3.3%)<br>CNS: 29/30 (96.7%) |
| **KIEDROWSKI 2013** | Hospital | 20 iPads | Detection of C. diff, MRSA | S. aureus: 3/20 (15%)<br>C. diff: 0/30 (0%)<br>Gram-negative: 0/30 (0%) |
| **LU 2009** | All ward stations of university hospital | 282 stations (keyboard and mouse) | Detection of S. aureus, Pseudomonas, Acinetobacter | MRSA: 3/282 (1.1%)<br>MSSA: 15/282 (5.3%)<br>A. baumannii: 12/282 (4.3%)<br>Other Acinetobacter: 10/282 (3.5%)<br>Pseudomonas: 17/282 (6%) (but none were P. aeruginosa) |
| **MESSINA 2013 (A)** | 4 different medical units | 27 keyboards | Total bacteria count of: Staphylococcus, Pseudomonas, E. coli, total coliform bacteria, C. diff, Acinetobacter | Acinetobacter: 1 (3.7%)<br>E. coli: 11 (40.7%)<br>Coliforms: 21 (77.8%)<br>Enterococci: 4 (14.8%)<br>Staphylococci: 25 (92.6%)<br>MRSA: 6 (22.2%)<br>Molds: 20 (74.1%) |
| **OGUZKAYA-ARTAN 2015** | ED | 14 keyboards + 5 desktop surfaces | Detection of S. aureus | MRSA: 1/14 (7%) |
| **OIE 2005** | Dermatology ward | 1 keyboard | Detection of S. aureus | MRSA: 0/4 (0%) |
| **OTTER 2011** | Hospital ED and an outpatient HIV clinic | Unknown number of keyboards | Detection of MRSA | MRSA identified on 3 keyboards in the ED and 0 keyboards in the HIV outpatient clinic. |
| **PHUMISANTIP HONG 2009** | Hospital patient rooms and nurse station | 30 computer terminals (keyboards/mice) | Detection of CRAB | A. baumannii: 3.3% (none were CRAB) |
| **REEM 2014** | Exam and imaging rooms, common areas in ophthalmology clinic | 16 keyboards | Detection of MRSA/MSSA | S. aureus: 7/24 (29.2%)<br>MRSA: 1/24 (4.2%)<br>MSSA: 5/24 (20.8%) |
| **SENOK 2015** | ICU nursing stations | Unknown number of keyboards and mice | Detection of A. baumannii isolates | One MRAB isolate identified on a computer mouse |
| **STAMBAUGH 2009** | Dental office | 88 keyboards or mice | Detection of Multidrug-resistant organisms | S. aureus: 8/88 (9%)<br>Lactose-fermenting gram-negative rods: 22/88 (25%)<br>CNS: 78/88 (88.6%) |

| | | | | |
|---|---|---|---|---|
| | | | | Bacillus: 23%<br>Enterococcus: 2%<br>Gram-negative rods: 2% |
| **TROCHESSET 2012** | School of Dental Medicine | Unknown number of keyboards and mice | Detection of S. aureus | S. aureus:<br>Keyboards: 4/47 (8.5%)<br>Mice: 0/4 (0%) |
| **XU 2017** | Medical ICU and neonatal ICU | Unknown number of keyboards and mice | Detection of MRSA | MRSA: 7/19 (36.8%) |

Abbreviations: A. baumannii = Acinetobacter baumannii, C. Diff = Clostridium difficile, CNS = Coagulase-negative staphylococcus, CRAB = Carbapenem-resistant Acinetobacter baumannii, E. Coli = Escherichia coli, ED = Emergency department, ICU = Intensive care unit, MRSA = Methicillin-resistant Staphylococcus aureus, MSSA = Methicillin-sensitive Staphylococcus aureus, MSSE = Methicillin-susceptible Staphylococcus epidermidis, OR = Operating room, P. aeruginosa = Pseudomonas aeruginosa, S. aureus = Staphylococcus aureus, VRE = Vancomycin-resistant Enterococcus

## Supplementary File 7: Studies reporting proportion of devices contaminated at baseline with specific types of microbes (including pathogens)

| AUTHOR, YEAR | DEVICE AND NUMBER | OUTCOME MEASURES | OVERALL BASELINE CONTAMINATION PREVALENCE | ALL S. AUREUS | MRSA | MSSA | ENTERO-COCCI: NON-VRE, OR NOT SPECIFIED | VRE | SKIN BACTERIA * | OTHER GRAM POSITIVES ** | GRAM NEG. RODS/ BACILLI *** | ENTERO-BACTER | C. DIFF | COLIFORMS NON-LACTOSE FERMENTERS **** | OTHERS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **ALBRECHT 2013** | 10 iPads | Total bacterial load | 1842 total CFU found on iPads in the clinical setting (162 median CFU) | | | | | | Micrococci: 25.7% | | | | | | All staphy-lococci: 59.9% |
| **ALI 2015** | Unknown number of keyboards | Detection of C. diff | C.diff detected using Brazier's contact plate: 0/5 (0%) Using Sponge swab: 3/15 (20%) | | | | | | | | | | 3/15 (20%) | | |
| **ANASTASIADES 2009** | 14 keyboards (K) and 14 mice (M) | Detection of CNS, Gram-positive bacilli, micrococci, fungi and S. aureus | | Round 1 K: 0/14 (0%) Round 1 M: 1/14 (7.1%) | | | | | Round 1 K: 14/14 (100%) Round 1 M: 14/14 (100%) | | | | | | |
| **BURES 2000** | 10 keyboards *specific pathogen rates include 8 faucet handles (144 samples) | Total bacterial load | 19/80 keyboard samples taken (24%) | | 16/144 (11.1%) | | 6/144 (4.2%) | | | | 7/144 (4.9%) | 4/144 (2.8%) | | | |
| **CATANO 2012** | 30 keyboards | Total bacterial load | 39 isolations from 30 keyboards; 56.4% | | | | 3/39 (7.7%) | | Bacillus: 17/39 (43.5%) MRSE: | | 3/39 (7.7%) | | | | Either MSSE, MSSA, MSSW, |

| AUTHOR, YEAR | DEVICE AND NUMBER | OUTCOME MEASURES | OVERALL BASELINE CONTAMINATION PREVALENCE | ALL S. AUREUS | MRSA | MSSA | ENTERO-COCCI: NON-VRE, OR NOT SPECIFIED | VRE | SKIN BACTERIA * | OTHER GRAM POSITIVES ** | GRAM NEG. RODS/ BACILLI *** | ENTERO-BACTER | C. DIFF | COLIFORMS NON-LACTOSE FERMENTERS **** | OTHERS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | were potentially clinically relevant | | | | | | 2/39 (5.1%) | | | | | | MSSH: 14/39 (35.9%) |
| **CIRAGIL 2006** | 56 keyboards in clinical areas | Total bacterial load | | | | 1/56 (1.8%) | 7/56 (12.5%) | | MSSE 23/56 (41.1%), Bacillus spp. 21/56 (37.5%), Corynebacterium 1/56 (1.8%) | Streptococus sp 1/56 (1.8%) | E. Coli 4/56 (7.1%), Klebsiella ozanae 1/56 (1.8%) Sphingomonas 1/56 (1.8%) | | | | |
| **CORDEIRO 2015** | 6 keyboards | Total bacterial load | 6/6 (100%) | | | | | | Non-spec CNS: 5/6 (83.3: 5/6 (83.3%) S. epi: 1/6 (16.7%) | | | | | | |
| **DANCER 2008** | 2 keyboards (52 total samples) | ACC greater than 2.5 CFU/cm$^2$ or any site with presence of MSSA or MRSA | 13/52 | | 1/52 | 2/52 | | | | | | | | | |

| AUTHOR, YEAR | DEVICE AND NUMBER | OUTCOME MEASURES | OVERALL BASELINE CONTAMINATION PREVALENCE | ALL S. AUREUS | MRSA | MSSA | ENTERO-COCCI: NON-VRE, OR NOT SPECIFIED | VRE | SKIN BACTERIA * | OTHER GRAM POSITIVES ** | GRAM NEG. RODS/ BACILLI *** | ENTERO-BACTER | C. DIFF | COLIFORMS NON-LACTOSE FERMENTERS **** | OTHERS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **DE GROOD 2012** | 230 keyboards | Total bacterial load | 99.6% (229/230) positive for one of CNS, Micrococcus, diptheroids, Bacillus spp. or alpha strep. And: 67% positive with any one of: MSSA, MRSA, Enterococcus (non VRE and VRE), GNB, C. diff, Yeast, fungus | | 17/230 (7.4%) | 21/230 (9.1%) | 58/230 (25.2%) | 9/130 (3.9%) | 229/230 (99.6%) | | 68/230 (29.6%) | | 0 (0%) | 21/230 (9.1%) | Yeast/ fungus: 5/230 (2.2%) |
| **DEVINE 2001** | 25 terminals (keyboard + mouse + pad) | Detection of MRSA | MRSA: 24% (42% in hospital A and 8% in hospital B) | | 6/25 (24%) | | | | | | | | | | |
| **DUMFORD 2009** | 32 compu-ters | C. diff | 9/32 (28%) contaminated with C. diff | | | | | | | | | | 9/32 (28%) | | |
| **DUSZAK 2014** | 7 mice | Total bacterial load | 100% had bacterial growth (mean colony counts: 46.1 ± 58.1) | 5/7 (71.4%) | | | | | CNS: 2/7 (28.6%) | | 2/7 (28.6%) | | | | |
| **ENGELHART 2008** | 77 computer terminals in clinical areas | Total bacterial load | Not reported for keyboards separately | 10/77 (13%) | | | 7/77 (9.1%) | | | Viridans streptococci: 8/77 (10.4%) | 13/77 (16.9%) | | | | Molds: 17/77 (22.1%) |

| AUTHOR, YEAR | DEVICE AND NUMBER | OUTCOME MEASURES | OVERALL BASELINE CONTAMINATION PREVALENCE | ALL S. AUREUS | MRSA | MSSA | ENTERO-COCCI: NON-VRE, OR NOT SPECIFIED | VRE | SKIN BACTERIA * | OTHER GRAM POSITIVES ** | GRAM NEG. RODS/ BACILLI *** | ENTERO-BACTER | C. DIFF | COLIFORMS NON-LACTOSE FERMENTERS **** | OTHERS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **FAIRES 2012** | Unknown number of keyboards | Detection of MRSA or C Diff | Medical wards: MRSA: between 8.2% and 14.8% C.Diff: 0 to 3.9% Surgical wards: MRSA: 12.5% to 13.2% C.Diff: 1.5% to 6.2% | | 4 (6.4%) | | | | | | | | 3 (4.8%) | | |
| **FAIRES 2013** | Unknown number of keyboards | Detection of MRSA or C. Diff (55 samples) | | | 1/55 (1.8%) | | | | | | | | 3/55 (5.5%) | | |
| **FELLOWES 2006** | 44 keyboards | Detection of MRSA or MSSA | MSSA: 9/44 (20%) MRSA: 4/44 (9%) | | 4/44 (9%) | 9/44 (20%) | | | | | | | | | |
| **GERBA 2016** | 17 computer touch screens | Coliform bacterial growth | Average number of bacteria: 2,257 CFU | | | | | 2/17 (12%) | S. epi: 6/17 (35%), Micrococc. luteus: 3/17 (18%), Micrococcus sp: 1/17 (6%), kytococcus sedentarius 2/17 (12%), S. caprae: 1/17 (6%), Kocuria varians: 1/17 (6%) | | Klebsiella: 2/17 (12%) | | 2/17 (12%) | | |

| AUTHOR, YEAR | DEVICE AND NUMBER | OUTCOME MEASURES | OVERALL BASELINE CONTAMINATION PREVALENCE | ALL S. AUREUS | MRSA | MSSA | ENTERO-COCCI: NON-VRE, OR NOT SPECIFIED | VRE | SKIN BACTERIA * | OTHER GRAM POSITIVES ** | GRAM NEG. RODS/ BACILLI *** | ENTERO-BACTER | C. DIFF | COLIFORMS NON-LACTOSE FERMENTERS **** | OTHERS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **GOSTINE 2016** | 40 keyboards (230 total samples) | Total bacterial load | 193/203 (95.1%) of samples positive for bacteria, median of 120 CFUs per keyboard | 12/203 (5.9%) | 3/203 (1.5%) | | 8/203 (3.9%) | 2/203 (1%) | | | Klebsiella 3/203 (1.5%) | 6/203 (3%) | | Pseudomonas: 1/203 (0.5%), Acinetobacter: 1/203 (0.5%) | |
| **GRABSCH 2012** | Unknown number of keyboards | Detection of VRE | 1/9 (11%) swabs were VRE positive | | | | | 1/9 (11%) | | | | | | | |
| **GRAY 2007** | 7 mice (63 samples) | Total bacterial load | 54/63 (85.7%) samples positive | 2/63 (3%) | | | | | CNS: 52/63 (83%), Micrococcus: 36/63 (57%), Bacillus: 26/63 (41%) | | | | | | Coccobacillus: 7/63 (9%) |
| **HARTMANN 2004** | Unknown number of keyboards (K) and mice (M)<br><br>238 samples taken of each | Potentially pathogenic microorganisms (2+ CFU) | (In patient rooms + central ward):<br><br>Keyboards: 15/238 (6.3%)<br>Mice: 13/238 (5.5%) | K: 3/238 (1.3%)<br><br>M: 15/238 (6.3%) | | | K: 12/238 (5%)<br><br>M: 2/238 (0.9%) | | K: Micrococcus: 134/238 (56.3%), S. Epi: 205/238 (86.1%) Other Staph sp: 78/238 (32.8%)<br><br>M: Micrococcus: 65/238 (27.3%), | | K: 2/238 (0.8%)<br><br>M: 0/238 | | | | Mold: K: 5/238 (2.1%)<br><br>M: 2/238 (0.8%) |

| AUTHOR, YEAR | DEVICE AND NUMBER | OUTCOME MEASURES | OVERALL BASELINE CONTAMINATION PREVALENCE | ALL S. AUREUS | MRSA | MSSA | ENTERO-COCCI: NON-VRE, OR NOT SPECIFIED | VRE | SKIN BACTERIA * | OTHER GRAM POSITIVES ** | GRAM NEG. RODS/ BACILLI *** | ENTERO-BACTER | C. DIFF | COLIFORMS NON-LACTOSE FERMENTERS **** | OTHERS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | S. Epi: 182/238 (76.5%), Other Staph Sp: 60/238 (25.2%) | | | | | | |
| **HASSAN 2014** | 150 keyboards and 100 mice | Total bacterial load | 242/250 (99.2%) | 198 (79.2%) | | | 93 (37.2%) | | S. Epi 172 (68.8%) | Strepto coccus 28 (11.2%) | GNB 201 (80.4%) E. Coli 45 (18%) | | | | |
| **HIRSCH 2014** | 30 iPads | Total bacterial load | | 22/30 (73.3%) | 15/30 (50%) | | 30/30 (100%) | 1/30 (3.3%) | CNS: 29/30 (96.7%) | | | | | | |
| **HONG 2012** | 112 items (56 keyboards and 56 mice) | Total bacterial load | 103/112 (92.0%) Keyboards: 98.2% Mice: 85.7% | | K: MRSA: 2/56 (1.8%) | K: MSSA: 2/56 (1.8%) | | | K: CNS: 51/56 (91.1%) Bacillus: 14/56 (25%) Micrococcus: 13/56 (23.2%)<br><br>M: CNS: 45/56 (80.4%) Bacillus: 5/56 (8.9%) Micrococcus: 6/56 (10.7%) | | M: GNR: 1/56 (0.9%) | | | | K: Molds: 3/56 (2.7%) |

| AUTHOR, YEAR | DEVICE AND NUMBER | OUTCOME MEASURES | OVERALL BASELINE CONTAMINATION PREVALENCE | ALL S. AUREUS | MRSA | MSSA | ENTERO-COCCI: NON-VRE, OR NOT SPECIFIED | VRE | SKIN BACTERIA * | OTHER GRAM POSITIVES ** | GRAM NEG. RODS/ BACILLI *** | ENTERO-BACTER | C. DIFF | COLIFORMS NON-LACTOSE FERMENTERS **** | OTHERS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **KARBASIZ-ADE 2014** | 65 Keyboards | Total bacterial load | 64/65 (98.5%) | 15/65 (23.1%) | 10/65 (15%) | | | | Bacillus: 45/65 (69.2%), CNS: 16/65 (24.6%), Micrococcus: 5/65 (7.7%) | Actinomycet sp: 1/65 (1.5%) | E. coli: 1/65 (1.5%) | 1/65 (1.5%) | | Citrobacter: 2/65 (3.1%), A. baumannii: 3/65 (4.6%) | |
| **KEERASUN TONPONG 2017** | 26 keyboards | Total bacterial load | 25/26 (96.2%) | | | | | | CNS: 25/26 (96.2%) Bacillus spp: 8/26 (30.8%) | Gram pos bacilli: 1/26 (3.8%) | NF-GNB: 3/26 (11.5%) | | | | Fungi: 8/26 (30.8%) |
| **KHAN 2015** | 106 portable electronic devices (93 were tablets) | Total bacterial load | 100% had at least 1 positive culture from screen or cover | 11/106 (10.4%) | | | 3/106 (2.8%) | | | | 7/106 (6.6%) | 1/106 (0.9%) | | 3/106 (2.8%) | |
| **KIEDROWSKI 2013** | 20 iPads | Detection of C.diff, MRSA | 3/20 (15%) iPads grew S aureus. No growth of C. diff. nor any gram-negative pathogens | 3/20 (15%) | | | | | | | 0 | | 0 | | |
| **LU 2009** | 282 stations (keyboard + mouse) | S. aureus, Pseudomonas sp, Acinetobacter sp. | 49/282 (17.4%) positive for S. aureus, Acinetobacter spp. or Pseudomonas spp | | 3/282 (1.1%) | 15/282 (5.3%) | | | | | | | | 29/282 (10.3%) | |

| AUTHOR, YEAR | DEVICE AND NUMBER | OUTCOME MEASURES | OVERALL BASELINE CONTAMINATION PREVALENCE | ALL S. AUREUS | MRSA | MSSA | ENTERO-COCCI: NON-VRE, OR NOT SPECIFIED | VRE | SKIN BACTERIA * | OTHER GRAM POSITIVES ** | GRAM NEG. RODS/ BACILLI *** | ENTERO-BACTER | C. DIFF | COLIFORMS NON-LACTOSE FERMENTERS **** | OTHERS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **MAN 2002** | 85 keyboards + 80 mice + 44 pads | Total bacterial load | 40 keyboards (47%), 36 mice (45%), and 15 mouse pads (34%) yielded multiple bacterial species. | 27/209 (12.9%) | 2/209 (1%) | | 14/209 (6.7%) | | Bacillus: 123/209 (58.9%) Staph epi: 103/209 (49.3%) | Strep spp: 16/209 (7.7%) | 26/209 (12.4%) | | | Pseudo-monas spp: 3/209 (1.4%) | |
| **MESSINA 2013 (A)** | 27 computer keyboards | Total bacteria count of: Staphyloccus spp, Pseudomonas spp, E. coli, total coliform bacteria, Acinetobacter spp, C.diff | | 25/27 (92.6%) | 6/27 (22.2%) | | 4/27 (14.8%) | | | | E .coli: 11/27 (40.7%) | | | Coliform 21/27 (77.8%) | Molds: 20/27 (74.1%) |
| **MESSINA 2013 (B)** | 50 keyboards | Total bacterial load | With PCA 36°C: 49/50 (98%) With PCA 22°C: 33/50 (66%) | 47/50 (94%) | 8/50 (16%) | | 5/50 (10%) | | | | E coli: 17/50 (34%) | | | Coliform 39/50 (78%) | Molds: 26/50 (52%) |
| **OGUZKAYA-ARTAN 2015** | 14 keyboards + 5 desktop surfaces | S. aureus isolates | 1/14 (7%) were MRSA positive | | 1/14 (7%) | | | | | | | | | | |
| **OIE 2005** | 1 keyboard | S. aureus isolates | MSSA: 3.3 +/- 7.5 (mean, S.D.) on 4 samples | | 0/4 (0%) | | | | | | | | | | |

| AUTHOR, YEAR | DEVICE AND NUMBER | OUTCOME MEASURES | OVERALL BASELINE CONTAMINATION PREVALENCE | ALL S. AUREUS | MRSA | MSSA | ENTERO-COCCI: NON-VRE, OR NOT SPECIFIED | VRE | SKIN BACTERIA * | OTHER GRAM POSITIVES ** | GRAM NEG. RODS/ BACILLI *** | ENTERO-BACTER | C. DIFF | COLIFORMS NON-LACTOSE FERMENTERS **** | OTHERS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **PHUMISANTIPHONG 2009** | 30 computer terminals (keyboard + mice) | Detection of CRAB | keyboards/mice at nurse station had lowest contamination rate of A. baumannii (3.3%) of all the sampled locations. No CRAB identified. | | | | | | | | | | | 3.3% | |
| **PUGLIESE 2011** | 72 keyboards | Total bacterial load | 10/72 (13.8%) colonized with 9 different bacteria | | 1/72 (1.4%) | 1/72 (1.4%) | | 1/72 (1.4%) | | | 9/72 (12.5%) includes E. coli, Pseudomonas, Sphing, Pantoea, and 2 without ID | | 0/72 | | |
| **REEM 2014** | 16 keyboards (24 total samples) | MRSA /MSSA isolates | 7/24 (29.2%) samples positive for MSSA, MRSA, or MRSP | 7/24 (29.2%) | 1/24 (4.2%) | 5/24 (20.8%) | | | | | | | | | |
| **RUTALA 2006** | 25 keyboards | Total bacterial load | 100% had at least one potential pathogen | 2/25 (8%) | ORSA 1/25 (4%) | OSSA 1/25 (4%) | 3/25 (12%) | 0 | CNS 25/25 (100%) Diphtheroids 20/25 (80%) Micrococcus 18/25 (72%) Bacillus 16/25 (64%) Propioniba | Alpha streptococci 6/25 (21%) Viridans streptococci 2/25 (8%) | | | | NF-GNR 9/25 (36%) | Fungi 6/25 (24%) |

| AUTHOR, YEAR | DEVICE AND NUMBER | OUTCOME MEASURES | OVERALL BASELINE CONTAMINATION PREVALENCE | ALL S. AUREUS | MRSA | MSSA | ENTERO-COCCI: NON-VRE, OR NOT SPECIFIED | VRE | SKIN BACTERIA * | OTHER GRAM POSITIVES ** | GRAM NEG. RODS/ BACILLI *** | ENTERO-BACTER | C. DIFF | COLIFORMS NON-LACTOSE FERMENTERS **** | OTHERS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | cteria 7/25 (28%) | | | | | | |
| **SCHULTZ 2003** | 100 keyboards | Total bacterial load | 95/100 (95%) had growth of 1+ microorganisms | 1/100 (1%) | | | 3/100 (3%) | 1/100 (1%) | CNS: 84/100 (84%) Bacillus sp: 44/100 (44%) Corynebact 8/100 (8%) | Strepto cocci: 9/100 (9%) | 6/100 (6%) | | | 2/100 (2%) | Clostridium perfringens: 4/100 (4%) |
| **SHAIKH 2016** | 25 keyboards | Total bacterial load | 20/25 (80%) contaminated with any potential pathogen | 2/25 (8%) | | | 15/25 (60%) | | | | 1/25 (4%) | | 2/25 (8%) | | |
| **SMITH 2006** | 60 notebook keys and grips | Total bacterial load | 52/120 (43%) cultures positive, but significant pathogens were found in only 2/120 (1.7%) of cultures | | | 1/120 (0.8%) | | | CNS 39/120, Diphtheroids-coryne bacterium 5/120, Micrococcus 13/120 | Alpha-hemolytic strep 4/120 | Serratia 1/120 (0.8%) | | | | |
| **STAMBAUGH 2009** | 88 keyboards or mice | Detection of Multidrug-resistant organisms | | 8/88 (9%) | | | 2/88 (2%) | | Bacillus: 20/88 (23%) CNS: 78/88 (88.6%) | | Lactose fermenting GNR: 22/88 (25%) Other GNR: 2/88 (2%) | | | | |

| AUTHOR, YEAR | DEVICE AND NUMBER | OUTCOME MEASURES | OVERALL BASELINE CONTAMINATION PREVALENCE | ALL S. AUREUS | MRSA | MSSA | ENTERO-COCCI: NON-VRE, OR NOT SPECIFIED | VRE | SKIN BACTERIA * | OTHER GRAM POSITIVES ** | GRAM NEG. RODS/ BACILLI *** | ENTERO-BACTER | C. DIFF | COLIFORMS NON-LACTOSE FERMENTERS **** | OTHERS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **SWEENEY 2009** | 68 computer terminals (keyboard + mice) | Total bacterial load | 67/68 (98.5%) showed some growth | | | 10/68 (14.7%) | | | | | | | | | |
| **TAN 2013** | Unknown number of keyboards (6 total samples) | Presence of MRSA, E. coli and K. pneumoniae resistant to third-gen cephalosporins, CRAB, VRE. | 6/6 (100%) | | 6/6 (100%) | | | 0/6 (0%) | | | Ceph-R Klebsiella spp. 0/6 (0%) | | | CRAB: 1/6 (17%) | |
| **TROCHESS-ET 2012** | Unknown number of keyboards and mice | Detection of S. aureus | | K: 4/47 (8.5%) M: 0/4 (0%) | | | | | | | | | | | |
| **WAGHORN 2005** | 48 keyboards | Total bacterial load (especially S. aureus, hemolytic strepto-cocci, P. aeruginosa and C.diff) | 100% grew organisms of some kind. 79% grew either moderate or heavy numbers of organisms. | | 1/48 (2%) | | | | 46/48 (96%) | | 12/48 (25%) | | 1/48 (2%) | 0 | Misc (including: Bacillus sp, fungal): 25/48 (52%) |
| **WESTERWAY 2017** | 10 ultra-sound keyboards | Total bacterial load | 100% of samples had 10 or more colonies (highest level of contamination) | | | | 3/10 (30%) | | | | | | | 7/10 (70%) | |

| AUTHOR, YEAR | DEVICE AND NUMBER | OUTCOME MEASURES | OVERALL BASELINE CONTAMINATION PREVALENCE | ALL S. AUREUS | MRSA | MSSA | ENTERO-COCCI: NON-VRE, OR NOT SPECIFIED | VRE | SKIN BACTERIA * | OTHER GRAM POSITIVES ** | GRAM NEG. RODS/ BACILLI *** | ENTERO-BACTER | C. DIFF | COLIFORMS NON-LACTOSE FERMENTERS **** | OTHERS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **WILSON 2006** | 17 keyboards<br><br>(51 total samples) | Total bacterial load | 100% contaminated with at least one species. | | 11/51 (21%) | 3/51 (5.9%) | | | CNS: 51/51 (100%) Bacillus: 47/51 (92%) | | 30/51 (59%) | | | | |
| **XU 2017** | Unknown number of keyboards and mice | Detection of MRSA | 7/19 (36.8%) swabs positive for MRSA. | | 7/19 (36.8%) | | | | | | | | | | |

* Skin bacteria includes: (S. epidermidis, CNS, S. Caprae, diptheroids, Micrococcus, Bacillus, Kytococcus, Corynebacter, Propionibacteria, kocuria varians)

** Gram positives: Alpha-hemolytic strep, Streptococci, Sphingomonas

***Gram negative rods/bacilli includes: (E.coli, Klebsiella, Serratia)

**** Coliforms non-lactose fermenters: (Pseudomonas, Proteus, Acinetobacter, Citrobacter)

Abbreviations: A. baumannii = Acinetobacter baumannii, ACC = Aerobic Colony Counts, C. Diff = Clostridium difficile, CFU = Colony forming units, CNS = Coagulase-negative staphylococcus, CRAB = Carbapenem-resistant Acinetobacter baumannii, E. Coli = Escherichia coli, GNB = Gram Negative Bacilli, MRSA = Methicillin-resistant Staphylococcus aureus, MRSP = Methicillin-resistant Staphylococcus pseudintermedius, MSSA = Methicillin-sensitive Staphylococcus aureus, MSSE = Methicillin-sensitive Staphylococcus epidermidis, MSSH = Methicillin-sensitive Staphylococcus hyicus, MSSW = Methicillin-sensitive Staphylococcus warneri, NF-GNR = Non-Fermenting Gram-Negative Rods, ORSA = Oxacillin-resistant Staphylococcus aureus, OSSA Oxacillin-sensitive Staphylococcus aureus, P. aeruginosa = Pseudomonas aeruginosa, PCA = Plate count agar, S. aureus = Staphylococcus aureus, S. caprae = Staphylococcus caprae, S.D. = Standard deviation, S. epi = Staphylococcus epidermidis, VRE = Vancomycin-resistant Enterococcus

## Supplementary File 8: Studies reporting interventions without statistically significant reductions in contamination of computer peripherals or had unclear effectiveness outcomes

| STUDY | OUTCOME MEASURES | INTERVENTION METHOD | BASELINE CONTAMINATION | POST-INTERVENTION CONTAMINATION | P-VALUES | COMMENTS |
|---|---|---|---|---|---|---|
| **CORDEIRO 2015** | Total bacterial load | Computer keyboards were cleaned on a daily basis with a brush for removing dust. | 6/6 (100%) | All 6/6 contained Non-specified coagulase negative Staphylococcus post cleaning with dust brush. | Not reported | *No statistical significance of these changes reported* |
| **DANCER 2009** | Detection of S. aureus species (MSSA and MRSA), overall aerobic colony counts (ACC) | Enhanced cleaning: an additional cleaner was added to the ward and trained to clean hand-touch sites 1-3x/day Monday to Friday. | | Enhanced cleaning was associated with a 32.5% reduction in levels of microbial contamination at hand touch sites (results not specific to keyboards) MRSA was isolated from 1 keyboard during intervention phase. | P < 0.0001: 95% CI 22.2%, 42.9% (for all hand touch sites including keyboards) | *Statistically significant reduction in contamination, but results not specific to keyboards* |
| **DE GROOD 2012** | Total bacterial load | CaviWipes (a quaternary ammonium compound) with isopropanol) | 2 studies:<br>1) Pre/Post with 230 keyboards: 229/230 (99.6%) contaminated with CNS, Micrococcus spp., diptheroids, Bacillus spp. or alpha streptococci and 67% total keyboards positive with solid agar and broth any one cultures (MSSA, MRSA, Enterococcus (non VRE and VRE), GNB, C. diff., Yeast, fungus)<br>2) Cleankeys keyboards: 10/10 (100%) | 1) 35/230 (15.2%) still positive for pathogenic organisms, including 3 with C. diff.<br>2) 0/10 (0%) positive for pathogenic organisms. | Not reported | *No statistical significance of these changes reported* |
| **DUMFORD 2009** | Detection of C. difficile | Disinfection with bleach | 9/32 (28%) keyboards were contaminated with C. diff. | 4/25 (16%) keyboards and 0/1 mouse were contaminated with C. diff. | P = 0.18, but this is for all surfaces tested, not only keyboards | *Statistically significant reduction in contamination, but results not available for keyboards separately* |
| **GRABSCH 2012** | Detection of VRE | Hospital wide program including 'Bleach-Clean': replace surface cleaners with sodium hypochlorite solution plus Chloradet detergent; install | 1/9 swabs were VRE positive (11%) | Decreased in Period B: 1/78 (1.3%) swabs positive | P = 0.012 for reduction of all environmental contamination, not specific to keyboards | *Statistically significant reduction in contamination, but results not available for* |

| STUDY | OUTCOME MEASURES | INTERVENTION METHOD | BASELINE CONTAMINATION | POST-INTERVENTION CONTAMINATION | P VALUES | COMMENTS |
|---|---|---|---|---|---|---|
| | | cleaner dispensing stations, employment of cleaning supervisors and training program for cleaning staff, performance appraisals, modify protocols for managing VRE-colonized patients, thrice annual schedule of "super clean disinfection" | | | | *keyboards separately* |
| **JUNGNICKEL 2014** | Total bacterial load | Isopropanol wipes using the 6-step disinfection process guided by the deBac-app. | 2,033 CFU in total were counted on the 5 devices before disinfection during the four week monitoring period:<br>Gram positive: 1,950 CFU<br>Gram negative: 83 CFU | Decreased to a total of 87 CFU found on the devices during the four week monitoring period:<br>gram positive: 86 CFU<br>gram negative: 1 CFU | | *No statistical significance of these changes reported* |
| **MORTER 2011** | Detection of Norovirus | Actichlor plus solution | Not reported | After cleaning, NoV was detected on 4/10 (40%) of keyboards and 1/8 (12.5%) of mice.<br><br>After a second cleaning, 1/4 (25%) of keyboards remained positive and 0/3 (0%) of mice remained positive. | | *No baseline level of contamination, therefore change cannot be determined. However, even after first cleaning, 40% of keyboards were contaminated, suggesting poor effect* |
| **SMITH 2006** | Total bacterial load | Clorox disinfecting wipes | 52/120 (43%) of cultures positive, but significant pathogens were found in only 1.7% of cultures (MSSA and Serratia species) | 18/46 (39%) of cultures were positive for various organisms, but no significant pathogens were isolated | P 0.799 | *Non-statistically significant reduction in contamination* |
| **STAMBAUGH 2009** | Detection of Multidrug-resistant organisms | Disinfectant wipes (ammonium chloride and isopropyl alcohol) | Overall rate not given | Both conventional and sealed keyboard/mice experienced a reduction in detectable organisms when disinfected 3x/day.<br>CNS: reduced from 88.6% in baseline to 5% in sealed keyboards and 25% in conventional keyboards. | | *No statistical significance of these changes reported* |

| STUDY | OUTCOME MEASURES | INTERVENTION METHOD | BASELINE CONTAMINATION | POST-INTERVENTION CONTAMINATION | P VALUES | COMMENTS |
|---|---|---|---|---|---|---|
| | | | | Lactose fermenting GNR reduced from 25% in baseline to 10% in sealed keyboards and 0% in conventional. Bacillus reduced from 23% in baseline to 10% in sealed keyboards and 0% in conventional keyboards<br>All other organisms were reduced 100% | | |
| **SWEENEY 2009** | Total bacterial load | Astroplast Nano-UV disinfectant light scanner | 67/68 (98.5%) showed some growth | 62/68 (91%) showed some growth after disinfection | | *No statistical significance of these changes reported* |

Abbreviations: ACC = Aerobic Colony Counts, C. Diff = Clostridium difficile, CFU = Colony forming units, CNS = Coagulase-negative staphylococcus, GNB = Gram Negative Bacilli, GNR = Gram Negative Rods, MRSA = Methicillin-resistant Staphylococcus aureus, MSSA = Methicillin-sensitive Staphylococcus aureus, NoV = Norovirus, VRE = Vancomycin-resistant Enterococcus

## Supplementary File 9: Studies reporting the effect of decontamination interventions on patient infection rates

| STUDY | STUDY DESIGN | INTERVENTION METHOD | EFFECT ON INFECTION OR COLONIZATION RATE |
|---|---|---|---|
| **DANCER 2009** | Prospective Cross-over | Enhanced cleaning: an additional cleaner was added to the ward and trained to clean hand-touch sites 1-3 times per day | Reduction in rate of new MRSA infections from 9 of 327 MRSA patient days during normal cleaning, to 4 of 475 patients days during enhanced cleaning, a reduction of 26.6% (95% CI 7.7%, 92.3%) (P=0.032). |
| **GRABSCH 2012** | Pre-Post | Hospital wide program including 'Bleach-Clean' | 24.8% reduction in newly recognized VRE colonizations: 208/1948 patients screened vs 324/4035, (P = 0.001). |
| **NEELY 1999** | Pre-Post | All personnel required to wear gloves before using the computer and removed before leaving the room, plus a defined daily cleaning procedure for plastic keyboard covers provided to housekeeping staff | 13 acquired colonizations and 16 total colonizations in the 5 months pre-intervention vs. 4 acquired colonizations and 14 total colonizations of Acinetobacter baumannii in the 7 months post-intervention (p <0.05). |
| **RASTOGI 2012** | Cross sectional taken biweekly for 1 year | During the study period, blood, respiratory, and cerebrospinal fluid cultures from admitted NICU patients were sent if clinically indicated. If positive, they were temporally correlated with the matching surveillance cultures. | 6 of the 48 (12.5%) positive blood cultures matched the organism growing from the surveillance sites, but the correlation was not significant (P=0.076).<br>None of the 31 positive respiratory cultures, nor the single positive cerebrospinal fluid culture correlated to organisms grown from the NICU environment. |
| **WILSON 2011** | Prospective randomized cross-over | Enhanced cleaning of hand contact surfaces - trained hygiene technicians performed an extra twice daily cleaning using cloths soaked in a copper-based biocidal formulation. | No effect on incidence of patient acquisition of MRSA (OR, 0.98; 95% CI, 0.58– 1.65; p = 0.93) |

Abbreviations: MRSA = Methicillin-resistant Staphylococcus aureus, VRE = Vancomycin-resistant Enterococcus

| | Objectives | | Sample Selection | | | | Detection methods |
|---|---|---|---|---|---|---|---|
| | Is the aim/objective of the study clearly described? | Was the ideal study design chosen to meet the aims? | Were selection criteria for the devices pre-specified, clearly described, and implemented consistently? | Were the devices in the study representative of the general or clinical population of interest? | Was the number of examined items stated and/or an inclusion rate given? | Was a power calculation prespecified to guide sample size? | Were the swabbing and lab processes clearly stated and consistently performed across all devices? |
| **Al-Hamad 2008** | Yes | Yes (Cross sectional) | No | Yes | No | No | Yes |
| **Ali 2015** | Yes | Yes (Cross sectional) | Yes | Yes | No | No | Yes |
| **Anastasiades 2009** | Yes | Yes (Cross sectional) | No | Yes | Yes | No | Yes |
| **Bures 2000** | Yes | Unclear (unclear if items were swabbed each time) | Yes | Yes | Yes | No | Yes |
| **Catano 2012** | Yes | Yes (Cross sectional) | No | Yes | Yes | No | Yes |
| **Choi 2014** | Yes | Yes (Cross sectional) | No | Yes | Yes | No | No |
| **Ciragil 2005** | Yes | Yes (Cross sectional) | No | Yes | Yes | No | Yes |
| **Dancer 2008** | Yes | Yes (Cross sectional, 1x week for 6 months per ward) | Yes | Yes | Yes | No | Yes |
| **Devine 2001** | Yes | Unclear design (possibly cross-sectional) | No | Yes | Yes | No | yes |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Engelhart 2008** | Yes | Yes (Cross sectional) | No | Yes | Yes | No | Yes |
| **Faires 2012** | Yes | Yes (Multiple cross sectional samples) | Yes | Yes | No | No | Yes |
| **Faires 2013** | Yes | Mixed - Cross sectional yes for prevalence aim but not for determining risk factors association | No (for keyboards) | Yes | No | No | Yes |
| **Farias 2017** | Yes | Yes (Cross sectional) | Unclear (text states items were sampled from each ward, but results only show keyboards in one ward) | Yes | Yes | No | Yes |
| **Fellowes 2006** | Yes | Yes (Cross sectional) | No | Yes | Yes | No | Yes |
| **Gerba 2016** | Yes | Yes (Cross sectional) | No | Unclear | Yes | No | Yes |
| **Gray 2007** | No | Yes (Cross sectional) | No | Yes | Yes | No | Yes |
| **Hardy 2014** | Yes | Yes, for contamination aim (Cross sectional) | Yes | Yes | No | No | Yes |
| **Hartmann 2004** | Yes | Yes (Cross sectional over 3 months) | No | Yes | No | No | Yes |
| **Hassan 2014** | Yes | Yes (Cross sectional) | No | Unclear | Yes | No | No |
| **Hirsch 2014** | Yes | Yes (Cross sectional) | Yes | Yes | Yes | No | Yes |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Hong 2012** | Yes | Yes (Cross sectional) | Yes | Yes | Yes | Yes | Yes |
| **Karbasizade 2014** | Yes | Yes (Cross sectional) | No | Unclear | Yes | Yes | Yes |
| **Keerasuntonpong 2017** | Yes | Yes (Cross sectional) | No | Yes | Yes | No | Yes |
| **Khan 2015** | Yes | No (Cross sectional) | No | No | Yes | No | Yes |
| **Kiedrowski 2013** | Yes | Yes (Cross sectional) | No | Unclear | Yes | No | No |
| **Link 2016** | Yes | Yes (Cross sectional with a control) | Yes | Yes | No (only # of samples) | Yes (for # of samples) | Yes |
| **Lu 2009** | Yes | Yes (Cross sectional) | No | Yes | Yes | No | Yes |
| **Malta 2016** | Yes | Yes (Cross sectional at 2 time points) | Yes | Yes | No | No | Yes |
| **Man 2002** | Yes | Yes (Cross sectional) | No | Yes | Yes | No | Yes |
| **Moore 2013** | Yes | Yes (Cross sectional over 17 weeks) | Yes | Yes | Unclear | No | Yes |
| **Motta 2007** | Yes | Yes (Cross sectional at 3x/day 1x/month over 1 year) | Yes | Yes | Yes | No | Yes |
| **Oguzkaya-Artan 2015** | Yes | Yes (Cross sectional) | No | Yes | Yes | No | No |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Oie 2005** | Yes | Yes (Cross sectional) | No | Yes | Yes | No | Yes |
| **Otter 2011** | Yes | Yes (Cross sectional) | No | Yes | No | No | Yes |
| **Phumisantiphong 2009** | Yes | No (Cross sectional) | Yes | Yes | Yes | No | No |
| **Pugliese 2011** | Yes | Yes (Cross sectional) | No | Unclear | Yes | No | No |
| **Rastogi 2012** | Yes | Unclear (Cross sectional taken biweekly for 1 year) | Yes | Yes | Yes | No | Yes |
| **Reem 2014** | Yes | Yes (Cross Sectional, quarterly for 1 year) | Yes | Yes | Yes | No | No (not specified which of the 2 swabbing methods was used on keyboards) |
| **Richard 2017** | Yes | Yes (Cross sectional) | Yes | Yes | Yes | No | Yes |
| **Rutala 2006** | Yes | Yes (Cross sectional) | No | Yes | Yes | No | Yes |
| **Saito 2015** | Yes | Yes (Cross sectional) | No | Yes | Yes | No | Yes |
| **Schultz 2003** | Yes | Yes (Cross sectional) | Yes | Yes | Yes | No | Yes |
| **Senok 2015** | Yes | Unclear | No | Yes | No | No | Nes |
| **Sykes 2006** | Yes | Yes, for the prevalence aim (Cross Sectional - 15x over 3 months) | No | Yes | Yes | No | Yes |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Tan 2013** | Yes | Yes, for the prevalence aim (Cross Sectional) | No | Yes | No | No | Yes |
| **Trochesset 2012** | Yes | Yes (Cross sectional) | No | Yes | No | No | Unclear (not clear how many times each object was sampled) |
| **Waghorn 2005** | Yes | Yes (Cross sectional) | No | Yes | Yes | No | Yes |
| **Westerway 2017** | Yes | Yes (Cross sectional) | No | Yes | Yes | No | Yes |
| **Wilson 2006** | Yes | Yes (Cross sectional) | Yes | Yes | Yes | No | Unclear (number of swabs varied because some patients were discharged or died) |
| **Yun 2012** | Yes | Yes (Cross sectional) | No | Yes | Unclear if given # is samples or keyboards/ mice | No | Yes |

| Outcome Measures | | | Confounding |
|---|---|---|---|
| Were the outcomes measured at multiple time points? | Were findings for all primary outcomes reported? | Are the estimates of prevalence or incidence given with confidence intervals and in detail by subgroup, if appropriate? | Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)? |
| Yes | Yes | No | Unclear |
| No | Yes | No, but gives Mean no. of CFU/cm² ± SD | Some<br>Compared sampling techniques: contact plate vs. Sponge swab |
| Yes | Yes | No | No |
| Yes | Yes | No | Unclear |
| No | Yes | No | No |
| Mixed/Unclear | Yes | No | No |
| No | Yes | No | No |
| Yes | Yes | No | Yes |
| No | Yes | No | No |

| | | | |
|---|---|---|---|
| No | Yes | No<br>Gives mean, median CFU values | Yes (# of users, ward vs. ICU, time used before sampling, room type) |
| Yes | Yes | No - CI given only for total rate of all surfaces sampled | Yes (surface location, type of surface, hospital (3 studied) |
| Yes | Yes | No | No |
| Yes | Yes | No | No (not specific to keyboards) |
| No | Yes | No | No |
| No | Yes | No | No |
| Yes | Yes | No | Yes (any significant differences in the # of colonies from the 3 areas sampled) |
| Yes | Yes | No | No |
| Yes | Yes | No | Yes (patient room vs. physician's station, patient room vs central workstation) |
| No | Yes | No | Yes (single user vs. multiple user) |
| No | Yes | Yes | Yes (hospital vs. non-hospital setting) |

| | | | |
|---|---|---|---|
| No | Yes | Yes | No (hand hygiene and contact studied, but not statistically adjusted for |
| No | Yes | No | No |
| No | Yes | No | Yes (compared patient areas vs. offices) |
| No | Unclear - some findings reported, but data not shown. | No | Mixed - some data not shown at one institution, differences between specialties |
| No | No S. aureus reported, but not MRSA | No | No |
| Yes | No | No | Yes (high touch vs. low touch areas, minutes of surgery) |
| No | Yes | No | Yes (non-ICU vs. ICU, accounting vs. clinical use) |
| Yes | Yes | No (but mean, med, min, max given) | Some (before/after clinical procedures) |
| No | Yes | No | No |
| Yes | Unclear - not all results reported for keybaords (only in one ward) | No | Some - zones of distance from patient |
| Yes | Yes | Yes, but overall baseline rate not stated, only by subgroup | Some (samples taken before, during, and after clinical procedures) |
| No | Yes | No | No |

| | | | |
|---|---|---|---|
| Yes | Yes | No (but mean SD given) | No |
| No | Yes | No | No |
| No | Yes | No | No |
| No | Yes | No | Some (specific keyboard location) |
| Yes | Yes | No | No (did study temporal association of positive blood cultures with positive surveillance cultures) |
| Yes | Yes | No | No |
| No | Yes | No (RLU mean, SD, min/max given) | No but compared keyboards to contamination on other surfaces |
| No | Yes | No | No (CFU range given) |
| No | Yes, but not always specific by subgroup, including keyboards | No (ATP mean value and SD given) | Yes, but these results specific to keyboards not provided |
| No | Yes | No | No |
| No | Yes | No | No |
| Yes | Overall cont. rate not given for keyboards, but isolated pathogens listed | No | No |

| | | | |
|---|---|---|---|
| No | Yes | No | No |
| Yes | Yes | No | Yes, some looked at the number of positive sites for S. aureus at different dates and at personal vs nonpersonal surfaces |
| No | Yes | No | No |
| No | Yes | No | No |
| Yes | Yes | No (but median and range of CFU given) | No |
| No | Yes | No | No |

| | Objectives | | Sample Selection | | | | |
|---|---|---|---|---|---|---|---|
| | Is the aim/objective of the study clearly described? | Was the ideal study design chosen to meet the aims? | Were selection criteria for the devices pre-specified, clearly described, and implemented consistently? | Were the devices in the study representative of those who would be eligible for the intervention in the general or clinical population of interest? | Was the number of examined items stated and/or an inclusion rate given? | Was a power calculation prespecified to guide sample size? | Was loss to follow-up after baseline 20% or less? |
| **Albrecht 2013** | Yes | Yes (Prospective comparative analysis) | Yes | Yes | Yes | Yes | Yes |
| **Codish 2015** | Yes | Yes (Cluster RCT) | No | Yes | Yes | No | Yes |
| **Cordeiro 2015** | Yes | No (Pre/Post) | No | Yes | Yes | No | Yes |
| **Dancer 2009** | Yes | Yes (Prospective Cross-over) | Yes | Yes | Yes | Yes | Unclear |
| **de Grood 2012** | Yes | No (Cross sectional + Pre/Post) | Yes | Yes | Yes | No | Yes |
| **Dumford 2009** | No - aims do not mention the post-cleaning survey | No (Cross sectional + Pre/Post) | Yes | Yes | Yes | No | No - not all keyboards were used in -post study |
| **Duszak 2014** | No - aims do not mention the post-cleaning survey | Mixed… (Cross sectional + Pre/Post) | No, clearly described but not consistently implemented | Yes | Yes | No | No - not all keyboards were used in -post study |
| **Fukada 2008** | Yes | No (Pre/Post) | No | Yes | No | No | No - not all keyboards were used in -post study |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Gostine 2016** | Yes | No?<br>(Pre/Post) | Yes | Yes | Yes | No | Yes |
| **Grabsch 2012** | Yes | No<br>(Pre/Post) | No | Yes | No | No | Unclear - looks like there were more sites during intervention |
| **Jones 2015** | Yes | Yes<br>(Controlled Trial) | Yes | Yes | Yes | No | Yes |
| **Jungnickel 2014** | Yes | No<br>(Pre/Post) | No | Yes | Yes | No | Yes |
| **Martin 2011** | Yes | Yes<br>(Randomized double blind cross-over trial) | Yes | Yes | Yes | No | Yes |
| **Messina 2013 (Env)** | Yes | No<br>(Pre/Post) | Yes | Yes | Yes | No | Yes |
| **Messina 2013 (Impact)** | Yes | No<br>(Pre/Post) | Yes | Yes | Yes | No | Yes |
| **Morter 2011** | Yes | No<br>(Post-Intervention survey) | Yes | Unclear<br>(Only conducted where there were NoV outbreaks) | Yes | No | Unclear |
| **Neely 1999** | No | No<br>(Pre/Post) | No | Yes | No | No | Unclear |
| **Patel 2010** | Yes | No<br>(Cross sectional + Pre/Post) | No | Yes | Yes | No | No - only 2 keyboards were used in post interv. study |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Shaikh 2016** | Yes | No (Pre/Post) | No | Unclear | Yes | No | Yes |
| **Smith 2006** | Yes | No Pre/Post | Yes | Yes | Yes | No | No - not all keyboards were used in -post study |
| **Stambaugh 2009** | Yes | No Pre/post with stratfied groups | Yes | Yes | Yes | No | No - not all keyboards were used in -post study |
| **Sweeney 2009** | Yes | No (Pre/Post) | No | Yes | Yes | No | Yes |
| **Wilson 2008** | Yes | Yes (Controlled trial) | Yes | Yes | Yes | Yes | Yes |
| **Wilson 2011** | Yes | Yes (Prospective randomized cross-over) | Yes | Yes | No | No | Yes |
| **Xu 2017** | Yes | No (Pre/Post) | No | yes | No | No | much higher in interv. than baseline (19 v. 206 samples) |

| Intervention | | Comparison/Controls | | Detection Methods | |
|---|---|---|---|---|---|
| Was the intervention clearly described and delivered consistently across the study population? | Was the timeframe appropriate so that one could reasonably expect to see an association between exposure and outcome if it existed? | Was there a comparison or control group? | If yes, explain what the comparison was. | Were the outcome assessors (swabbing and lab) blinded to the intervention or exposure status of participants? | Were the swabbing and lab processes clearly stated and consistently performed across all devices? |
| No | Yes | No | | Yes | Yes |
| Yes | Yes | Yes | 1 group disinfected with Mediwipes, another with TriGene wipes | Unclear | Yes |
| No | Yes | Yes | Pre and post samples compared. | Unclear | Yes |
| Yes | Yes | Yes | Two matched wards selected, the intervention conducted 6 months in one, then 6 months in the other | Unclear | Yes |
| Yes | Yes | Yes | CleanKeys keyboard vs. conventional keyboards | Unclear | Yes |
| No | Yes | Yes | A sample of surfaces were sampled again 14 months after initial survey (after a disinfection protocol was initiated) | Unclear | Yes |
| Mixed - clearly described but not delivered to all keyboards in initial sample | Yes | Yes | At 1 workstation in each of the 4 reading rooms, sampling was repeated after being disinfected. | Unclear | Yes |
| Mixed - clearly described but not delivered to all keyboards in initial sample | Yes | Yes | Keyboards in the OR were swabbed after health procedure vs. 1 hour after cleaning | Unclear | Yes |

| | | | | | |
|---|---|---|---|---|---|
| Yes | Unclear (study explored range of types of disinfection cycles and time delays) | Yes | Keyboards tested prior to cleaning vs. keyboards disinfected using UV Angel lamps | Unclear | Mixed: Swabbing process defined, but not lab |
| Yes | Unclear (poorly described) | Yes | Outcomes were assessed during the 6 months pre and 12 months post implementation | Unclear | No, swabbing timing not clear or done consistently throughout pre- period |
| Yes | Yes | Yes | In ICU: Pre and post swabs with both CHG spray and stadard methods In wards: Swabs taken before and after CHG intervention | Mixed: lab persons blinded only | Yes |
| Unclear - disinfection process done "as (care staff) saw fit" | Yes | Yes | Samples taken before and after internvetion | Unclear | No |
| Yes | Yes | Yes | UV light treated keyboards vs. Existing keyboards vs. non-UV control keyboards | Yes | Yes |
| Yes | Yes | Yes | Pre-and post disinfection samples taken | Unclear | Yes |
| Yes | Yes | Yes | Pre-and post disinfection samples taken | Unclear | Yes |
| Yes | Yes | No | | Unclear | Yes |
| Yes | Yes | Yes | A. baumannii colonizations pre and post infection control measures | Unclear | Unclear |
| Yes | Yes | Yes | 2 of the keyboards were swabbed after being disinfected twice daily | Unclear | Yes |

| | | | | | |
|---|---|---|---|---|---|
| Yes | Yes | Yes | keyboards swabbed before and after UV decontamination | Unclear | Yes |
| No | Yes | Yes | Swabs from desktop computers in hallway were compared with physician notebooks.<br>Also, some notebooks compared pre/post cleaning | No | Yes |
| Yes | Yes | Yes | 3 groups:<br>- not disinfected<br>- conventional keyboards disinfected 3x/day<br>- Sealed keyboards disinfected 3x/day | Unclear | Yes |
| Yes | Yes | Yes | Devices swabbed before and after disinfection | Unclear | Yes |
| Yes | Yes | Yes | 2 types of test keyboards vs. standard control keyboard | Unclear | No |
| Yes | Standard vs. enhanced cleaning | Yes | Yes | Unclear | Yes |
| Yes | Yes | Yes | Baseline period: daily routine cleanings vs. Intervention period using 2 types of disinfectant wipes | Unclear | Yes |

| Outcome Measures | | | | Confounding |
|---|---|---|---|---|
| Were the outcome measures pre-specified, clearly defined, valid, reliable, and assessed consistently using reliable methods across all devices? | Was the outcome measured multiple times before the intervention and multiple times after the intervention? (Or were multiple samples taken from each intervention group?) | Were findings for all primary outcomes reported? | Did statistical methods examine changes in outcome measures from before to after the intervention? Were statistical tests done that provided p values for the pre-to-post changes? | Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)? |
| Yes | No | Yes | Yes | Unclear |
| Yes | No | Yes | Yes | Unclear |
| No | No | No | No | No |
| Yes | Yes | Yes - but baseline specific to keyboards not given | Yes | No |
| Yes | No - twice before cleaning, once after | Yes | No | No |
| Yes | No | Yes | Yes, but for all surfaces tested, not only keyboards | No |
| Yes | No | Yes | Yes (but not for keyboards separately) | No |
| Yes | No | Yes | Yes | No |

| | | | | |
|---|---|---|---|---|
| Yes | Yes | Yes | Yes | No, but effect of UV cycle length and delay options reported |
| Yes | Yes | Yes | Yes, but for all surfaces tested, not only keyboards | No |
| Yes | Yes | Yes | Yes | No |
| Yes | Yes | Yes | No | No |
| Yes | No | Yes | Yes | Yes, some |
| Yes | No | Yes | Yes | Yes, some such as type of clinical setting |
| Yes | No | Yes | Yes | No |
| Yes | No | Yes | No | No |
| No | N/A | N/A | Yes | No |
| No<br>(only did aerobic cultures not anerobic too) | No | Yes | Yes | No |

| | | | | |
|---|---|---|---|---|
| Yes | No | Yes | Yes | No |
| Yes | No | No | Yes | No |
| Yes | Yes | Yes | No | No |
| Yes | No | Yes | No | No |
| Yes | Yes | Yes | Yes | No |
| Yes | Yes | Unclear for keyboards | Unclear for keyboards | Mostly no (timing of sampling assessed, seasons) |
| Yes | Yes | No | Yes | No |

BMJ Open

# What's on your keyboard? A systematic review of the contamination of peripheral computer devices in healthcare settings



| | |
|---|---|
| Journal: | *BMJ Open* |
| Manuscript ID | bmjopen-2018-026437.R1 |
| Article Type: | Research |
| Date Submitted by the Author: | 15-Jan-2019 |
| Complete List of Authors: | Ide, Nicole; University of Washington, Department of Family Medicine<br>Frogner, Bianca; University of Washington, Family Medicine<br>LeRouge, Cynthia; Florida International University, Department of Information Systems & Business Analytics<br>Vigil, Patrick; Pacific Northwest University<br>Thompson, Matthew; University of Washington, Department of Family Medicine |
| Primary Subject Heading: | Infectious diseases |
| Secondary Subject Heading: | Infectious diseases, Health informatics, Health services research |
| Keywords: | Infection control < INFECTIOUS DISEASES, Health & safety < HEALTH SERVICES ADMINISTRATION & MANAGEMENT, contamination, healthcare-acquired infection, nosocomial infection, keyboard |
| | |

# What's on your keyboard? A systematic review of the contamination of peripheral computer devices in healthcare settings

Nicole Ide[1], Bianca K. Frogner[1], Cynthia M. LeRouge[2], Patrick Vigil[3], Matthew J. Thompson[1]

[1] Department of Family Medicine, University of Washington, Seattle, WA 98195-4696 USA

[2] Department of Information Systems & Business Analytics, Florida International University, Miami, FL 33199, USA

[3] Pacific Northwest University, Yakima, WA 98901, USA

**Corresponding Author:**

Matthew J. Thompson, mjt@uw.edu, +1-206-616-8149

University of Washington, Family Medicine, Box 354696, Seattle WA 98195-4696

**Word Count:** 3,515

**Keywords**: contamination, healthcare-acquired infections, Nosocomial Infection, keyboards, cross infection, infection control

**ABSTRACT**

**Objective** To determine the extent and type of microbial contamination of computer peripheral devices used in healthcare settings, evaluate the effectiveness of interventions to reduce contamination of these devices, and establish the risk of patient and healthcare worker infection from contaminated devices.

**Design** Systematic Review

**Methods** We searched four online databases: MEDLINE, CINAHL, Embase, and Scopus for articles reporting primary data collection on contamination of computer-related equipment (including keyboards, mice, laptops, and tablets) and/or studies demonstrating the effectiveness of a disinfection technique. Pooling of contamination rates was conducted where possible, and narrative synthesis was used to describe the rates of device contamination, types of bacterial and viral contamination, effectiveness of interventions, and any associations between device contamination and human infections.

**Results** Of the 4,432 records identified, a total of 75 studies involving 2,804 computer devices were included. Of these, 50 studies reported contamination of computer-related hardware, and 25 also measured the effects of a decontamination intervention. The overall proportion of contamination ranged from 24% to 100%. The most common microbial contaminants were skin commensals, but also included potential pathogens including MRSA, C. difficile, VRE, and E. coli. Interventions demonstrating effective decontamination included wipes/pads using isopropyl alcohol, quaternary ammonium, Chlorhexidine, or dipotassium peroxodisulphate, UV-light emitting devices, enhanced cleaning protocols, and chlorine/bleach products. However, results were inconsistent, and there was insufficient data to demonstrate comparative effectiveness. We found little evidence on the link between device contamination and patient/healthcare worker colonization or infection.

**Conclusions** Computer keyboards and peripheral devices are frequently contaminated; however, our findings do not allow us to draw firm conclusions about their relative impact on transmission of pathogens or nosocomial infection. Additional studies measuring the incidence of healthcare-acquired infections from computer hardware, the relative risk they pose to healthcare, and evidence for effective and practical cleaning methods are needed.

**Strengths and limitations of this study:**

- This is the first systematic review on the level of contamination of computer peripheral devices used in clinical care as well as effectiveness of interventions used to decontaminate these surfaces.
- We searched four major online databases during the literature search and hand searched references of included studies and relevant review articles
- Reporting of this review adhered to the PRISMA guidelines
- The ability to perform meta-analysis was limited by the heterogeneity among included studies

## INTRODUCTION

The annual number of healthcare-acquired infections (HAIs) in U.S. acute care hospitals is estimated at approximately 722,000, or 4% of inpatients.[1] HAIs lead to longer admissions, more frequent re-admissions, and poorer patient outcomes including increased mortality.[2, 3] The U.S. Centers for Disease Control and Prevention (CDC) estimates that preventing HAIs in the U.S. would result in annual direct savings of between $5.7 and $31.5 billion.[4] Studies to date have largely focused on hospital settings, thus the frequency of consequences of HAIs in outpatient settings is poorly described.

Between 20% and 40% of HAIs result from cross-infection via hands of personnel, and another 20% from other environmental contamination.[5] Contamination of environmental surfaces in healthcare settings is a well-known source of nosocomial infection, and several pathogens have been identified on surfaces in hospital environments, including methicillin-resistant Staphylococcus aureus (MRSA), Clostridium difficile (C. diff), Acinetobacter baumannii, vancomycin-resistant enterococci (VRE), Pseudomonas aeruginosa, Norovirus, and gram-negative bacteria.[6-9] Nosocomial pathogens often originate from infected patients who come into contact with the surfaces surrounding them, particularly “high-touch surfaces”, and are then transferred to other healthcare workers’ or patients’ hands.

Several studies looking at healthcare workers’ personal devices (mobile phones or PDAs), clothing (neckties, white coats, etc.), and a variety of other objects (stethoscopes, blood pressure cuffs, telephones, faucets, bedrails, etc.) have found significant rates of environmental contamination.[6, 10, 11] However, the importance of contamination related specifically to computer keyboards, mice, and other computer peripherals is less well established despite their ubiquitous use in hospital and ambulatory healthcare settings.

We therefore conducted a systematic review to determine the extent to which computer keyboards, mice, and other computer peripheral devices have been identified as being a source of contamination in

clinical settings. We examine the type and prevalence of microbial contamination, and the settings in which these contaminated devices have been addressed. We also determined the effectiveness of interventions that aim to reduce contamination of these devices, and any evidence linking clinical consequences of HAI related to computer keyboards/peripherals among patients and healthcare workers.

## METHODS

We report this systematic review in accordance with the PRISMA guidelines, an evidence-based minimum set of items recommended for reporting of systematic reviews.[12] A PRISMA checklist can be found in **Supplementary File 1.**

### Search strategy

A total of four databases were included in our search: MEDLINE, CINAHL, Embase, and Scopus. We developed two major categories of search terms that were used in various combinations to search the databases. Firstly, terminology related to peripheral and external computer hardware devices, such as mice and keyboards. Secondly, terminology related to infection, contamination or disinfection (**Supplementary File 2)**. We conducted automated searches databases from January 1, 1990 through July 14, 2017. We limited the search to this time frame due to the low rates of computer use in clinical settings prior to 1990. Additionally, we manually searched the references of included studies and relevant review articles to identify further eligible studies, and where possible, we contacted authors to obtain full texts of abstracts if not available online.

### Eligibility criteria and study selection

We included studies that met the following criteria: a) conducted in any type of healthcare setting in a high- or upper middle-income country,[13] b) investigated keyboards, mice, mouse pads, computer

touch screens, laptops, and iPads/tablet computers, c) reported primary data collected through experimental, quasi-experimental, or observational study designs, d) reported contamination rates of computer-related equipment and/or demonstrated the effectiveness of disinfection technique(s), e) reported any association between contamination of computer-related equipment and infection or colonization of patients/healthcare workers, and f) written in English language.

We excluded studies which were not conducted in a healthcare setting or were conducted in low- or lower middle-income countries (where pathogenic microbes are potentially different to those found in high- or upper middle-income countries), tested computer related equipment with in vitro experiments, reported solely data on environmental surfaces other than computer-related hardware, or assessed healthcare worker knowledge or compliance with disinfection or hand-washing protocols. We excluded all studies that only provided an abstract.

After searching the four databases, we uploaded articles to EndNote X8 and removed any duplicates. One reviewer (NI) screened titles and abstracts to remove clearly irrelevant studies. Two reviewers (NI and MT) independently screened the full text of all remaining articles to determine final eligibility, and resolved any discrepancies through discussion and consensus.

**Data extraction and quality assessment**

Using a standardized form in Microsoft Excel, a single reviewer (NI) extracted the following data from each included article: country and clinical setting, study design, sampling frame and size, microbiological sampling method, microbiological identification method, outcome measure(s), intervention definition (if any), comparison (if any), ongoing decontamination methods (if any), and results (baseline contamination rates, baseline pathogens detected, post-intervention contamination rate). Extracted data were checked for accuracy by a second author (MT), and disagreements were resolved prior to analysis.

Two authors (NI and MT) independently assessed the methodological quality and risk of bias using checklists we developed based on The National Heart, Lung, and Blood Institute's (NHLBI) study quality assessment tool [14] as well as criteria developed in a relevant systematic review by Livshiz-Riven et al. which assessed the relationship between contamination and noninvasive portable clinical environmental surfaces.[15] To assess risk of bias for each outcome, we developed two separate checklists: one for studies reporting only baseline contamination and another for studies that included an intervention. We looked at the quality of individual studies and assessed the risk of bias on the basis of study design, objectives, sampling strategy, microbial detection methods, outcome measurement and reporting, and confounding variables. For studies of decontamination interventions, we also assessed intervention characteristics and comparisons or controls. Each assessment item was scored as "Yes", "No", or "Unclear". The overall risk of bias of the body of evidence was considered in interpretation of findings of the review.

**Summary measures**

For studies reporting contamination of peripheral computer-related hardware devices, we present findings as the proportion of devices contaminated, using definitions of contamination as reported in individual studies. For studies reporting effectiveness of a decontamination intervention, we present findings as a change (or percentage change) in contamination rates following the intervention, as reported by the respective authors. We explored whether there were differences in contamination rate between clinical settings, countries, or types of devices. We intended to use meta-analysis to pool results, but due to heterogeneity in study design, interventions, and outcomes reported, this was not possible. A simple pooled mean of baseline contamination of the studies which included an overall baseline rate of device contamination was calculated.

### Patient and public involvement

Neither patients nor the public were involved in the development of the research question or study design for this systematic review. Results will be made available to the public by publishing this study in a peer-reviewed, open access journal.

## RESULTS

### Study selection

Our search identified 4,416 records, with an additional 24 identified through a manual search. After removing duplicates, we screened the remaining 3,920 articles based on our inclusion criteria. Of these, 174 were selected for full-text review, of which 99 did not meet our criteria and were excluded, leaving a total of 75 studies in the final analysis (**Figure 1**).[16-90]

### Study characteristics

Of the 75 included studies (**Supplementary File 3**), only one was published prior to year 2000, with another 27 studies published between 2000-2009, and 47 studies published 2010 onwards. Most were conducted either in the USA or Canada (26) or Europe/Central Asia (28), followed by Southeast/East Asia or the Pacific (12), Middle East (4), South America (4), and South Africa (1).

The vast majority (63) of studies were conducted only in hospitals, including intensive care units (ICU) (12 conducted solely in ICU and an additional 17 studies included ICU as one of their settings), emergency department (ED) (11), and operating rooms (OR) (8). A further 12 studies were conducted in a variety of other clinical settings, including dental clinics or dental hospital, radiology settings, an outpatient ophthalmology clinic, a pharmacy practice, and two were in mixed hospital and outpatient settings.

Overall, the included studies provided data on a total of 2,804 devices, including 1,482 keyboards, 665 computer stations, and 398 mice or mouse pads. Nineteen studies did not explicitly state the number of devices tested or only reported the total number of samples taken. Keyboards were the most commonly studied peripheral computer device, with 42 studies testing keyboards alone and another 22 testing a combination of keyboards plus mice. Fewer tested tablets (5) or mice alone (2). The numbers of devices sampled ranged from a single keyboard up to 282 computer stations (keyboards plus mice).

The majority of studies (50) reported primarily on device contamination rates (mostly using cross-sectional samples).[17-23, 26, 29, 32-36, 38, 41-46, 49, 50, 52-56, 60, 62, 64-66, 68-76, 81-86, 90] Another 25 studies used interventional designs;[16, 24, 25, 27, 28, 30, 31, 37, 39, 40, 47, 48, 57-59, 61, 63, 67, 77-80, 87-89] most reported contamination rates before and after a disinfection or cleaning process (and therefore also contributed data on baseline contamination rates). One study only reported contamination post-intervention,[61] and another two reported only on an association between device contamination and patient colonization rates.[63, 88] Of the 25 studies reporting interventions, most used pre-post designs (17), with a smaller number (8) using controlled trials, post-intervention study, cross-over, or prospective comparative analysis. A variety of methods were used to measure effectiveness, including change in rate of overall contamination (11), change in rate of specific pathogens (5), change in colony forming unit (CFU) values (3), reduction in both rates and CFU values (2), rate of keyboards with contamination over 500 CFU (1), number of acquired colonizations pre- and post-intervention (1), patient acquisition of MRSA (1), and contamination rate for post-intervention phase only (1).

**Prevalence of baseline contamination**

A total of 71 studies provided data on levels of device contamination. Of these, 26 presented an overall proportion of microbial contamination (**Table 1**), with contamination rates ranging from 24% to 100%.

Of these 26 studies, 21 reported the proportion of devices contaminated, while five reported the proportion of collected swabs that were contaminated. Of the 21 studies reporting device contamination, the pooled mean contamination rate was 96.7% (range 80% to 100%).

**Table 1: Studies Reporting the Proportion of Computer Devices Contaminated**

| AUTHOR, YEAR | CLINICAL SETTING | DEVICE AND NUMBER | PROPORTION CONTAMINATED |
|---|---|---|---|
| **BURES 2000** | ICU (patient rooms, nurse + doctor stations)<br>USA | 10 keyboards<br>(80 total swabs) | 19/80 (24%) |
| **CODISH 2015** | Internal medicine wards and ICU<br>Israel | 81 keyboards + 81 mice | Internal medicine: 92/92 (100%)<br>ICU: 62/70 (88.6%)<br>Total: 154/162 (95.1%) |
| **CORDEIRO 2015** | ICU in medium sized hospital<br>Brazil | 6 keyboards<br>(12 total swabs) | 6/6 (100%) |
| **DE GROOD 2012** | Medical, surgical, ICU units in 4 urban hospitals<br>Canada | 2 studies:<br>1) 230 keyboards<br>2) 10 Cleankeys keyboards | 1) 229/230 (99.6%) contaminated with CNS, Micrococcus spp., diphtheroids, Bacillus spp. or alpha streptococci.<br>And: 67% keyboards positive with solid agar and broth any one cultures (MSSA, MRSA, Enterococcus (non VRE and VRE), GNB, C. diff., Yeast, fungus)<br>2) 10/10 (100%) |
| **DUSZAK 2014** | outpatient radiologist workstations in 2 hospitals in 2 U.S. states | 7 mice | 7/7 (100%) |
| **GOSTINE 2016** | ICU<br>USA | 40 keyboards<br>(203 total swabs) | 193/203 (95.1%) |
| **GRAY 2007** | ED at tertiary referral hospital<br>Northern Ireland | 7 mice<br>(63 total swabs) | 54/63 (85.7%) |
| **HASSAN 2014** | Staff rooms, computer labs, internet centers in a teaching hospital<br>Iraq | 150 keyboards and 100 mice | 242/250 (99.2%) |
| **HONG 2012** | ED of 3 teaching hospitals<br>South Korea | 56 keyboards and 56 electronic | 103/112 (92.0%) |
| **KARBASIZADE 2014** | Medical wards of various hospitals<br>Iran | 65 keyboards | 64/65 (98.5%) |
| **KEERASUNT-ONPONG 2017** | Patient care areas in general medical wards, ICU in a hospital<br>Thailand | 26 keyboards | 25/26 (96.2%) |
| **KHAN 2015** | two large academic institutions, medical centers<br>USA | 106 portable electronic devices<br>(93 iPads/ tablet) | 100% had at least 1 positive culture from screen or cover. |

| AUTHOR, YEAR | CLINICAL SETTING | DEVICE AND NUMBER | PROPORTION CONTAMINATED |
|---|---|---|---|
| **MARTIN 2011** | ICU and ED in pediatric hospital USA | 24 terminals (keyboards/ Mouse/Pad) | 23/24 (96%) |
| **MESSINA 2013 (B)** | Various units within 3 hospitals Italy | 50 keyboards | With PCA 36°C - 49/50 (98%) With PCA 22°C - 33/50 (66%) |
| **PATEL 2010** | 4 different areas of a dental hospital (2 student study areas, 2 clinics) UK | 8 keyboards | 100% contaminated with variety of microorganisms including S. aureus, CNS, GNR and cocci |
| **RICHARD 2017** | Orthopedic OR USA | 6 keyboards | 100% |
| **RUTALA 2006** | Burn ICU, cardiothoracic ICU, nursing units USA | 25 keyboards | 25 keyboards (100%) had growth of 2 or more microorganisms |
| **SCHULTZ 2003** | VA hospital: areas close to patients in high use areas of the acute, ambulatory, and long term care areas. USA | 100 keyboards | 95 of 100 (95%) |
| **SHAIKH 2016** | Lab and medical wards USA | 25 keyboards | 20/25 (80%) including GNB, C. difficile, Enterococcus spp, or S. aureus |
| **SMITH 2006** | Medical, surgical, family practice programs USA | 60 notebook keys and grips (120 total swabs) | 52/120 cultures (43%) contaminated. Significant pathogens found in only 1.7% of cultures (MSSA and Serratia species) |
| **SWEENEY 2009** | Various clinical wards and ED UK | 68 computer terminals (keyboards/mice) | 67/68 (98.5%) |
| **TAN 2013** | 2 open wards in 800 bed acute care hospital Singapore | Unknown number of keyboards 6 total samples | 6/6 (100%) |
| **WAGHORN 2005** | General medical, general surgical, orthopedic, care of the elderly, dermatology and pediatric wards, ICU, ED, OPD, and theatre suite. UK | 48 keyboards | 100% grew organisms of some kind. 79% of sampled computers grew either moderate or heavy numbers of organisms. |
| **WESTERWAY 2017** | Ultrasound units in public hospital and private practice Australia | 10 ultrasound keyboards | 100% of samples had 10 or more colonies (highest level of contamination) |
| **WILSON 2006** | ICU - bedside and nurse station UK | 17 keyboards | 100% contaminated with at least one species |
| **YUN 2012** | Patient care rooms in burn ICU and orthopedic ward USA | Unknown number of devices (total 32 samples from keyboards/mice) | 32/32 (100%) |

C. diff. = Clostridium difficile, CNS = Coagulase-negative staphylococcus, ED = Emergency department, GNB = Gram Negative Bacilli, GNR = Gram Negative Rods, ICU = intensive care unit, MRSA = Methicillin-resistant Staphylococcus aureus, MSSE = Methicillin-susceptible Staphylococcus epidermidis, OPD= outpatient department, OR = operating room, PCA = Plate count agar, S. aureus = Staphylococcus aureus, VRE = Vancomycin-resistant Enterococcus

A further 12 studies reported overall contamination only as CFU (**Supplementary File 4**), and another 10 reported contamination using a variety of other methods, such as proportion of devices with multiple bacterial species identified, mean bacterial counts, aerobic colony counts (ACC), or adenosine triphosphate (ATP) values/failures (**Supplementary File 5**). A further 23 studies reported baseline contamination of only a single or few specific pathogens: 20 as a proportion (%) of each pathogen, one presented total bacterial counts (mean ± SD), and two reported the existence of specific pathogens without quantifying them (**Supplementary File 6**).

The range of overall contamination was wide: while most studies found a contamination rate of 80%-100%, Bures et al. reported a rate of 24% in a study of keyboards in ICU patient rooms and nurse/doctor stations,[20] while Smith et al. reported a rate of 43% on notebook computers from medical, surgical, family practice programs.[78] However, we were unable to determine differences in contamination rates between clinical settings, countries, or types of devices due to insufficient data.

**Type of microbial contamination**

The specific pathogens isolated from keyboards or other computer devices was reported in 63 studies. Of these, 49 reported the proportion of devices contaminated with specific types of bacteria (**Supplementary File 7**). The most frequent microbial contaminants were skin commensal bacteria, but contamination with a variety of potentially pathogenic bacteria was also reported. The most frequent potential pathogens identified included Staphylococcus aureus (S. aureus) and MRSA, but this depended on whether studies set out to detect all microbe or pathogens, or only specific organisms. Of the studies reporting contamination with S. aureus, the mean contamination rate was 28% (range 1% – 94%). Mean rates of contamination with MRSA was 14% (range 0%-100%), VRE at 3.7% (range 0%-12%), and C. Diff at 8.0% (range 0%-28%).

**Effectiveness of decontamination interventions**

Twenty-five studies evaluated the effectiveness of disinfection or cleaning interventions on the level of device contamination. Of these, 14 reported statistically significant reductions in contamination following the intervention **(Table 2)**. These included seven studies using wipes/pads with isopropyl alcohol, quaternary ammonium, Chlorhexidine, or dipotassium peroxodisulphate;[16, 24, 31, 37, 47, 67, 89] three studies using UV light;[39, 57, 77] two studies using putty cleaning compound;[58, 59] one study with an enhanced cleaning protocol (including glove use);[63] and one study using a keyboard with a cleaning alarm.[87]

**Table 2: Studies Reporting Interventions Which Led to Significant Reduction in Contamination of Computer Peripheral Devices**

| STUDY | OUTCOME MEASURES | METHOD USED TO DECONTAMINATE | BASELINE CONTAMINATION | POST-INTERVENTION CONTAMINATION |
|---|---|---|---|---|
| **ALBRECHT 2013** | Total bacterial load | Isopropanol wipes using 6-step disinfection process guided by deBac-App. Control cleaned with new, dry "soft, lint-free cloth" | 1842 total CFU found on iPads in the clinical setting (162 median CFU) | Clinical setting: 98.1% reduction *(P=0.001)*<br>Nonclinical setting: 99.4% reduction *(P=0.001)*.<br>Control reduction rate 51.1% (p-value not reported) |
| **CODISH 2015** | Total bacterial load | MEDIWIPES (alcohol based) vs. TriGene (quaternary ammonium based). Each device decontaminated 3x/day | Internal medicine: 92/92 (100%)<br>ICU: 62/70 (88.6%)<br>Total: 154/162 (95.1%) | Internal medicine: 76/92 (82.6%)<br>ICU: 31/70 (44.3%)<br>Total: 107/162 (66%)<br>*P<0.001 for both Internal Med and ICU* |
| **DUSZAK 2014** | Total bacterial load | "Chlorascrub" pads (chlorhexidine gluconate and isopropyl alcohol) | Bacterial growth found on 100% of computer mice.<br>Mean colony counts: 46.1 ± 58.1 | "Demonstrable bacterial colonization was completely eradicated" for all 4 mice (100% reduction). |
| **FUKADA 2008** | Total bacterial load | Cotton cellulose sheet dampened with ethyl alcohol – *intervention only conducted in the OR* | Mean bacterial counts (SD):<br>OR: 333 (141)<br>ICU: 1015 (501)<br>Consulting room and OPD reception area: 1113 (1420) | In the OR: Mean (SD) total bacteria counts reduced significantly (from 333 (141) to 35 (67) cfu/mL)<br>*P< 0.05* |
| **GOSTINE 2016** | Total bacterial load | UV Angel Desktop lamps, set to 3-, 5-, 6-, and 10-min cycles | 193/203 (95.1%) samples, median of 120 CFUs per keyboard | 13/218 (6%) samples contaminated, a >99% reduction based on median CFU values (120 pre, 0 post). *P<0.0001* |
| **JONES 2015** | Total bacterial load | CHG spray (chlorhexidine gluconate, isopropyl alcohol) vs. TF spray (chlorine dioxide-based) | 57% of keyboards had contamination of >500 CFU (Included: Bacillus sp, CNS, micrococci, diphtheroids) | 2% of keyboards had a contamination of >500 CFU (*P ≤ 0.001)*<br>(only bacterial isolate was bacillus spp.) |
| **MARTIN 2011** | Total bacterial load | Keyboards with Vioguard UV light irradiation vs. identical control keyboards not exposed to UV light irradiation. | 23/24 (96%) had bacteria isolated | 8/24 (33%) had bacteria isolated. *P =0.001*,<br>(Primarily gram-positive human flora and gram-negative environmental flora. S aureus and P aeruginosa isolated from 2 control keyboards) |

| STUDY | OUTCOME MEASURES | METHOD USED TO DECONTAMINATE | BASELINE CONTAMINATION | POST-INTERVENTION CONTAMINATION |
|---|---|---|---|---|
| **MESSINA 2013 (A)** | Total bacteria count of: Staph., E. coli, Pseudomonas, total coliform bacteria, Acinetobacter, C. diff | Putty cleaning compound (ethanol 29%) with malleable-elastic consistency | Total microbial load *(at 2 different incubation temperatures):*<br>36°C: 26/27 (96.3%), CFU: 512<br>22°C: 25/27 (92.6%), CFU 557<br><br>Acinetobacter spp: 1 (3.7%)<br>E.coli: 11 (40.7%)<br>Coliforms: 21 (77.8%)<br>Enterococci: 4 (14.8%)<br>Staphylococci: 25 (92.6%)<br>MRSA: 6 (22.2%)<br>Molds: 20 (74.1%) | 36°C: 2/27 (7.4%), CFU: 3<br>22°C: 4/27 (14.8%), CFU: 18<br><br>Significant reductions in:<br>Coliforms: 2 (7.4%) *p< 0.0001*<br>Staphylococci: 1 (3.7%) *p< 0.0001*<br>Molds: 1 (3.7%) *p< 0.0001*<br>E.coli 0%, *p= 0.001*<br>*Borderline or non-significant reductions in:*<br>Enterococcus 0%: p= 0.045,<br>MRSA 0%: p = 0.014 |
| **MESSINA 2013 (B)** | Total bacterial load | Putty cleaning compound (ethanol 29%) with malleable-elastic consistency | Total microbial load: *(at 2 different incubation temperatures):*<br>36°C: 49/50 (98%)<br>22°C: 33/50 (66%)<br><br>E. coli: 17/50 (34%)<br>Coliforms: 39/50 (78%)<br>Enterococci: 5/50 (10%)<br>Staphylococci: 47/50 (94%)<br>MRSA: 8/50 (16%)<br>Molds: 26/50 (52%) | 36°C: 8/50 (16%)<br>22°C: 8/50 (16%)<br><br>Coliforms: 1 (2%)<br>Staphylococci: 2 (4%)<br>Molds: 1 (2%)<br>*Significant differences for all (p<0.001) after disinfection* |
| **NEELY 1999** | Detection of Acinetobacter species | Enhanced cleaning policy: required to wear gloves before using computer, plastic keyboard covers cleaned daily. | 13 acquired colonizations and 16 total colonizations of A. baumannii in 5 months pre-intervention | 10 acquired colonizations and 34 total colonizations of A. baumannii in 19 months post-intervention.<br><br>*The number of acquired A. baumannii colonizations post- intervention were significantly less than pre-intervention (P<.05).* |
| **PATEL 2010** | Total bacterial load | 70% isopropanol wipes vs. Virkon (dipotassium peroxodisulphate) | 100% contaminated with bacteria including S. aureus, coagulase negative staphylococci, Gram-neg rods and cocci. | 100% of C. albicans, P. aeruginosa and S. sanguinis removed<br>99.9% of S. epidermidis removed<br>96% of all the other organisms removed<br>*The number of organisms recovered after the intervention were significantly reduced (P< 0.001)* |
| **SHAIKH 2016** | Total bacterial load | UV Angel system | 20/25 (80%) contaminated with any potential pathogen, including gram-negative bacilli, C. diff, Enterococcus, or S. aureus. | 5/25 (20%) contaminated with any potential pathogen (*P = 0.0001)*<br>Total aerobic and facultative bacteria: 18/25 (72%) *(P=0.0006)* |
| **WILSON 2008** | Detection of S. aureus, Acinetobacter sp. | Medigenic keyboard (alarm when cleaning required), anonymous keyboard, vs standard keyboards | Fr Medigenic keyboards, baseline contamination rates ranged from 38-65 CFU, depending on alarm interval. Included: MRSA, Acinetobacter | Total viable count on Medigenic keyboards with alarm lower than other two types of keyboards. Median CFU reduced from 38 to 5. *P<0.0001* |
| **XU 2017** | Detection of MRSA | Cotton cloth and bucket system vs. disinfectant wipes | 7/19 (36.8%) keyboards and mice positive for MRSA. | 2/206 (1%) positive for MRSA. *P < 0.001* |

Abbreviations: C. diff. = Clostridium difficile, CFU = colony forming unit, ICU = intensive care unit, MRSA = Methicillin-resistant Staphylococcus aureus, OPD= outpatient department, OR = operating room, S. aureus = Staphylococcus aureus, SD = Standard deviation.

A further eight studies reported reductions in contamination from interventions **(Supplementary File 8)**, but reductions were not statistically significant,[78] not tested using statistical tests,[28, 48, 79, 80] or did not apply the statistical tests specific to data from the computer devices.[27, 30, 40] Effectiveness of interventions in an additional two studies was unclear due to poor reporting of baseline and/or post intervention contamination rates **(Supplementary File 8)**.[25, 61]

**Association between device contamination and clinical infection**

Only five included studies examined the association between device contamination and infection or colonization of patients/healthcare workers (**Supplementary File 9**). Of these, three reported an association, showing that the decontamination intervention was associated with reductions in the rate of MRSA infections,[27] VRE,[40] and Acinetobacter colonizations.[63] However, the link between association and causation in these studies was unclear and open to bias. One study showed that even though 12.5% of positive blood cultures matched the organisms growing from surveillance sites, this correlation was not significant,[70] and one showed no effect of a cleaning intervention on patient acquisition of MRSA.[88]

**Quality Assessment**

For studies that reported contamination rates, sampling methods were often convenience-based, and only six used a power calculation to guide sample size. In 19 studies, the number of included devices was not explicitly stated, and denominators were reported inconsistently. In 44 out of 75 studies, selection criteria for the devices were not given, were not clearly described or implemented consistently. In 29 of the 50 studies that only measured prevalence, samples were obtained at a single time point. Only four of the studies that reported effectiveness of decontamination interventions were controlled trials, with most using cross-sectional or pre-post designs. Reporting of effectiveness of interventions using statistical testing was poor or inconsistent. Few studies were designed in such a way that patient

outcomes could be measured, that is, the direct impact of contamination on HAI. Reporting of results was frequently poor, with only 26 studies reporting the overall number and percentage of computer-related devices with bacterial contamination. Of the 50 studies reporting only baseline contamination, only 10 studies provided a confidence interval or mean/median CFU, ATP or relative light unit (RLU) value of keyboards or computer peripherals sampled. Full risk of bias tables can be found in **Supplementary File 10.**

## DISCUSSION

To our knowledge, this is the first systematic review to report on the level of contamination of computer peripheral devices used in healthcare settings, as well as effectiveness of interventions used to decontaminate these items. This review fills an important gap and provides substantial evidence from 75 studies and a total of 2,804 devices that computer peripheral devices, particularly keyboards, are potential reservoirs of infective pathogens. The overall proportion of contamination ranged from 24% to 100%. Collectively, studies found a 96.7% contamination rate of keyboards sampled. Keyboards and other computer peripherals were most commonly contaminated with skin commensal bacteria, but also with a variety of other potential pathogenic bacteria including MRSA, C. difficile, VRE, and E. coli. Multiple interventions have been tested in attempts to decontaminate computer devices and keyboards in clinical settings, and several appear effective at reducing the overall level of contamination. Fourteen of the twenty-five interventional studies reported statistically significant reductions in contamination following the intervention. Effective interventions include: wipes/pads using isopropyl alcohol, quaternary ammonium, Chlorhexidine, or dipotassium peroxodisulphate, UV-light emitting devices, putty cleaning compounds, enhanced cleaning protocols, and a keyboard with a cleaning alarm. However, results were inconsistent and there was insufficient data to provide robust recommendations

on which method(s) are most effective to adopt routinely. Finally, there was insufficient data to demonstrate clear evidence of association between contamination and human infection.

Current data are mostly limited to hospital settings. Almost all (63) of the included studies were conducted solely in hospitals, with a particular focus on ICUs. Only a small number of studies were conducted solely in ambulatory or outpatient settings.

**Comparison to existing literature**

Our findings are consistent with a variety of literature on the potential contribution of contaminated hospital surfaces to human infection.[91] Not only can environmental surfaces harbor dangerous pathogens, but evidence shows that pathogens such as MRSA can be transferred to healthcare workers' gloves or hands from contaminated surfaces.[92-94] While some pathogens only survive a few days on inanimate surfaces, others, such as VRE, MRSA, Acinetobacter spp., and C. difficile can survive for months if not properly cleaned or disinfected.[95, 96] Furthermore, some pathogens, such as VRE or C. difficile, are more resistant to common disinfection methods than others. The link between environmental contamination and human infection has been difficult to establish firmly; however, various modelling studies, observational epidemiologic studies, interventional studies, as well as outbreak reports suggest this link exists.[7, 97, 98]

The optimal strategies for environmental disinfection in healthcare settings is unclear. Substantial evidence suggests that relying only on hand hygiene compliance among health workers is not an effective strategy. Two systematic reviews showed median rates of compliance with hand hygiene guidelines in hospital settings of 40% to 57%.[99, 100] Keyboards and computer devices pose additional challenges, including the difficulty of decontaminating their irregular surfaces and the potential for damage from cleaning products.[101] While multiple methods to decontaminate environmental surfaces generally have been developed, their effectiveness is unclear.[96, 98, 102, 103] Indeed, the

CDC's Guidelines for Environmental Infection Control in Health-Care Facilities (updated in 2011) concluded that "More research is required to clarify the effectiveness and reliability of fogging, UV irradiation, and ozone mists to reduce norovirus environmental contamination," giving it a "No recommendation/unresolved issue" rating.[104] Results from our review suggest that little progress has been made in providing robust evidence for decontamination methods.

**Limitations of the Review**

As with any systematic review, our findings are limited by the quantity and quality of included studies. Heterogeneity across a number of areas limited our ability to conduct meta-analysis and/or draw inferences from our findings. This included heterogeneity in the swabbing and microbiological identification methods, study settings, study timeframes, sample sizes, and types of included devices. Outcome measures also varied; for example, some studies did not report a baseline contamination rate, and others did not specify the prevalence of specific pathogens identified. Fewer than half of the studies reported selection criteria which was pre-specified, clearly described, and implemented consistently. Only one study specifically sought to identify viruses (Norovirus).[61] Many potential pathogens were not specifically assessed in the included studies, and the data may represent an underestimate of contamination rates. Finally, nearly all included articles were conducted in hospital environments, and we have limited data on ambulatory or primary care settings.

**Implications for researchers, clinicians and policy makers**

Our findings indicate that the majority of keyboards and computer peripherals used in healthcare settings are contaminated with a range of microbes, including potential pathogens. However, determining the impact of this contamination on patients or healthcare workers was limited. Although we searched for studies reporting associations between contamination of computer-related equipment and infection or colonization of patients/healthcare workers, very few studies (5) were identified and

the results of these were unclear and open to bias. Thus, our findings do not allow us to draw firm conclusions about the relative impact of these 'reservoirs' of contamination as sources of transmission between patients and healthcare staff, nor their impact on HAI or nosocomial infections. However, given that computers are ubiquitous in modern healthcare, it is possible that keyboards and peripherals may act as important, yet largely unrecognized sources of contamination and/or infection. Although evidence directly linking contaminated computer equipment and HAIs is scarce, evidence does demonstrate the effectiveness (albeit sometimes limited) of decontaminating potential fomites other than computer equipment as well as health workers' hands on reducing HAIs.[7, 97, 98, 105-107] Given this evidence, there is an urgent need to identify whether the same benefits apply to decontaminating computer equipment.

Our review highlights priorities for further research in this area. First, there seems to be little need to further demonstrate prevalence of contamination on computer related devices. In contrast however, the relative impact of computer device contamination on colonization and infection of patients/healthcare workers is unclear currently; thus, future research should focus on clinically significant organisms and their potential for transmission to patients or health workers. Additionally, more robust study designs are needed for evaluating decontamination interventions, particularly ones that could be used in routine practice.

In conclusion, computer keyboards and other peripheral computer devices in hospital settings are frequently contaminated, often with potentially pathogenic microbes. It is unclear from current research how often these lead to HAI, and what measures clinicians and their staff should take (and how often) to ensure that their computers are sufficiently clean and do not pose risks for themselves or their patients.

**Figure Legend:**

**Figure 1:** Flow Diagram of Study Selection

**Funding:** No grants or contracts were received to conduct this study.

**Competing Interests**: None declared.

**Acknowledgements**: Many thanks to Sarah Safranik for assisting with the search strategy for the literature review.

**Contributions**: NI and MT designed the study methodology and conducted the literature search. NI extracted data from selected studies and MT checked extracted data for accuracy. NI and MT performed data analysis and developed the original draft of the article and contributed towards further drafts. Data interpretation and critical revision of the manuscript was done by BF, CL, and PV. All authors reviewed and approved the manuscript.

**Data sharing statement**: The complete data extraction form, quality assessment tables, and full search strategy can be made available upon request to the study authors.

## REFERENCES


1. Magill SS, Edwards JR, Bamberg W, et al. Multistate point-prevalence survey of health care-associated infections. *N Engl J Med* 2014;370(13):1198-208. doi: 10.1056/NEJMoa1306801 [published Online First: 2014/03/29]
2. Umscheid CA, Mitchell MD, Doshi JA, et al. Estimating the proportion of healthcare-associated infections that are reasonably preventable and the related mortality and costs. *Infection control and hospital epidemiology* 2011;32(2):101-14. doi: 10.1086/657912 [published Online First: 2011/04/05]
3. Rahmqvist M, Samuelsson A, Bastami S, et al. Direct health care costs and length of hospital stay related to health care-acquired infections in adult patients based on point prevalence measurements. *American journal of infection control* 2016;44(5):500-6. doi: 10.1016/j.ajic.2016.01.035 [published Online First: 2016/03/19]
4. Scott R. The direct medical costs of healthcare-associated infections in US hospitals and the benefits of prevention. Atlanta, GA: Centers for Disease Control and Prevention, 2009.
5. Weinstein RA. Epidemiology and control of nosocomial infections in adult intensive care units. *The American journal of medicine* 1991;91(3b):179s-84s. [published Online First: 1991/09/16]
6. de Oliveira AC, Damasceno QS. Surfaces of the hospital environment as possible deposits of resistant bacteria: A review. *Revista da Escola de Enfermagem* 2010;44(4):1118-23. doi: 10.1590/S0080-62342010000400038
7. Otter JA, Yezli S, French GL. The role played by contaminated surfaces in the transmission of nosocomial pathogens. *Infect Control Hosp Epidemiol* 2011;32(7):687-99. doi: 10.1086/660363 [published Online First: 2011/06/15]
8. Weber DJ, Anderson D, Rutala WA. The role of the surface environment in healthcare-associated infections. *Curr Opin Infect Dis* 2013;26(4):338-44. doi: 10.1097/QCO.0b013e3283630f04 [published Online First: 2013/06/08]
9. Dancer SJ. The role of environmental cleaning in the control of hospital-acquired infection. *The Journal of hospital infection* 2009;73(4):378-85. doi: 10.1016/j.jhin.2009.03.030 [published Online First: 2009/09/04]
10. Brady RR, Verran J, Damani NN, et al. Review of mobile communication devices as potential reservoirs of nosocomial pathogens. *J Hosp Infect* 2009;71(4):295-300. doi: 10.1016/j.jhin.2008.12.009 [published Online First: 2009/01/27]
11. Haun N, Hooper-Lane C, Safdar N. Healthcare Personnel Attire and Devices as Fomites: A Systematic Review. *Infection Control and Hospital Epidemiology* 2016;37(11):1367-73. doi: 10.1017/ice.2016.192
12. Moher D, Liberati A, Tetzlaff J, et al. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med* 2009;6(7):e1000097. doi: 10.1371/journal.pmed.1000097 [published Online First: 2009/07/22]
13. World Bank. World Bank Country and Lending Groups 2017 [Available from: https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups accessed 11/7/2017.
14. National Heart Lung Blood Institute. Assessing cardiovascular risk: systematic evidence review from the Risk Assessment Work Group 2013 [Available from: https://www.nhlbi.nih.gov/sites/default/files/media/docs/risk-assessment.pdf accessed 7/20/2018.
15. Livshiz-Riven I, Borer A, Nativ R, et al. Relationship between shared patient care items and healthcare-associated infections: a systematic review. *International journal of nursing studies* 2015;52(1):380-92. doi: 10.1016/j.ijnurstu.2014.06.001 [published Online First: 2014/07/07]

16. Albrecht UV, Von Jan U, Sedlacek L, et al. Standardized, app-based disinfection of ipads in a clinical and nonclinical setting: Comparative analysis. *Journal of medical Internet research* 2013;15(8) doi: 10.2196/jmir.2643
17. Al-Hamad A, Maxwell S. How clean is clean? Proposed methods for hospital cleaning assessment. *Journal of Hospital Infection* 2008;70(4):328-34. doi: 10.1016/j.jhin.2008.08.006
18. Ali S, Muzslay M, Wilson P. A Novel Quantitative Sampling Technique for Detection and Monitoring of Clostridium difficile Contamination in the Clinical Environment. *Journal of clinical microbiology* 2015;53(8):2570-4. doi: 10.1128/jcm.00376-15 [published Online First: 2015/06/05]
19. Anastasiades P, Pratt TL, Rousseau LH, et al. Staphylococcus aureus on computer mice and keyboards in intensive care units of the Universitas Academic Hospital, Bloemfontein, and ICU staff's knowledge of its hazards and cleaning practices. *Southern African Journal of Epidemiology and Infection* 2009;24(2):22-26.
20. Bures S, Fishbain JT, Uyehara CF, et al. Computer keyboards and faucet handles as reservoirs of nosocomial pathogens in the intensive care unit. *American journal of infection control* 2000;28(6):465-71. doi: 10.1067/mic.2000.107267 [published Online First: 2000/12/15]
21. Cataño JC, Echeverri LM, Szela C. Bacterial contamination of clothes and environmental items in a third-level hospital in Colombia. *Interdisciplinary Perspectives on Infectious Diseases* 2012;2012 doi: 10.1155/2012/507640
22. Choi ES, Choi JH, Lee JM, et al. Is the environment of the endoscopy unit a reservoir of pathogens? *Intestinal research* 2014;12(4):306-12. doi: 10.5217/ir.2014.12.4.306 [published Online First: 2014/11/07]
23. Ciragil P, Gul M, Aral M. Bacterial contamination of computers and telephones in a university hospital in Turkey. The Journal of hospital infection. England2006:247-8.
24. Codish S, Toledano R, Novack V, et al. Effectiveness of stringent decontamination of computer input devices in the era of electronic medical records and bedside computing: a randomized controlled trial. *American journal of infection control* 2015;43(6):644-6. doi: 10.1016/j.ajic.2014.09.011 [published Online First: 2014/12/03]
25. Cordeiro ALAO, Oliveira MMC, Fernandes JD, et al. Equipment contamination in an intensive care unit. *ACTA Paulista de Enfermagem* 2015;28(2):160-65. doi: 10.1590/1982-0194201500027
26. Dancer SJ, White L, Robertson C. Monitoring environmental cleanliness on two surgical wards. *International journal of environmental health research* 2008;18(5):357-64. doi: 10.1080/09603120802102465 [published Online First: 2008/09/30]
27. Dancer SJ, White LF, Lamb J, et al. Measuring the effect of enhanced cleaning in a UK hospital: a prospective cross-over study. *BMC medicine* 2009;7(1):28. doi: 10.1186/1741-7015-7-28
28. De Grood J, Ward L, Harman S, et al. A cross-sectional point prevalence multi-hospital survey of health care associated pathogen contamination of computer keyboards. *Canadian Journal of Infectious Diseases and Medical Microbiology* 2012;23:13B.
29. Devine J, Cooke RP, Wright EP. Is methicillin-resistant Staphylococcus aureus (MRSA) contamination of ward-based computer terminals a surrogate marker for nosocomial MRSA transmission and handwashing compliance? *The Journal of hospital infection* 2001;48(1):72-5. doi: 10.1053/jhin.2001.0955 [published Online First: 2001/05/19]
30. Dumford DM, 3rd, Nerandzic MM, Eckstein BC, et al. What is on that keyboard? Detecting hidden environmental reservoirs of Clostridium difficile during an outbreak associated with North American pulsed-field gel electrophoresis type 1 strains. *American journal of infection control* 2009;37(1):15-9. doi: 10.1016/j.ajic.2008.07.009 [published Online First: 2009/01/28]

31. Duszak Jr R, Lanier B, Tubbs JA, et al. Bacterial contamination of radiologist workstations: Results of a pilot study. *Journal of the American College of Radiology* 2014;11(2):176-79. doi: 10.1016/j.jacr.2013.05.017
32. Engelhart S, Fischnaller E, Simon A, et al. Microbial contamination of computer user interfaces (keyboard, mouse) in a tertiary care centre under conditions of practice. *Hygiene + Medizin* 2008;33(12):504-07.
33. Faires MC, Pearl DL, Ciccotelli WA, et al. A prospective study to examine the epidemiology of methicillin-resistant Staphylococcus aureus and Clostridium difficile contamination in the general environment of three community hospitals in southern Ontario, Canada. *BMC infectious diseases* 2012;12:290. doi: 10.1186/1471-2334-12-290 [published Online First: 2012/11/10]
34. Faires MC, Pearl DL, Berke O, et al. The identification and epidemiology of meticillin-resistant Staphylococcus aureus and Clostridium difficile in patient rooms and the ward environment. *BMC infectious diseases* 2013;13:342. doi: 10.1186/1471-2334-13-342 [published Online First: 2013/07/26]
35. Fellowes C, Kerstein R, Clark J, et al. MRSA on tourniquets and keyboards. The Journal of hospital infection. England2006:86-8.
36. Farias PG, Gama F, Reis D, et al. Hospital microbial surface colonization revealed during monitoring of Klebsiella spp., Pseudomonas aeruginosa, and non-tuberculous mycobacteria. *Antonie van Leeuwenhoek* 2017;110(7):863-76. doi: 10.1007/s10482-017-0857-z [published Online First: 2017/03/25]
37. Fukada T, Iwakiri H, Ozaki M. Anaesthetists' role in computer keyboard contamination in an operating room. *The Journal of hospital infection* 2008;70(2):148-53. doi: 10.1016/j.jhin.2008.05.023 [published Online First: 2008/08/15]
38. Gerba CP, Wuollet AL, Raisanen P, et al. Bacterial contamination of computer touch screens. *American journal of infection control* 2016;44(3):358-60. doi: 10.1016/j.ajic.2015.10.013
39. Gostine A, Gostine D, Donohue C, et al. Evaluating the effectiveness of ultraviolet-C lamps for reducing keyboard contamination in the intensive care unit: A longitudinal analysis. *American journal of infection control* 2016;44(10):1089-94. doi: 10.1016/j.ajic.2016.06.012 [published Online First: 2016/08/16]
40. Grabsch EA, Mahony AA, Cameron DRM, et al. Significant reduction in vancomycin-resistant enterococcus colonization and bacteraemia after introduction of a bleach-based cleaning–disinfection programme. *Journal of Hospital Infection* 2012;82(4):234-42. doi: http://dx.doi.org/10.1016/j.jhin.2012.08.010
41. Gray J, Mc Nicholl B, Webb H, et al. Mice in the emergency department: Vector for infection or technological aid? *European Journal of Emergency Medicine* 2007;14(3):160-62. doi: 10.1097/MEJ.0b013e3280bef922
42. Hardy K, Abbott G, Bashford S, et al. Can measuring environmental cleanliness using ATP aid in the monitoring of wards with periods of increased incidence of Clostridium difficile? *J Infect Prev* 2014;15(1):31-35. doi: 10.1177/1757177413501568 [published Online First: 2014/01/01]
43. Hartmann B, Benson M, Junger A, et al. Computer keyboard and mouse as a reservoir of pathogens in an intensive care unit. *Journal of clinical monitoring and computing* 2004;18(1):7-12. doi: 10.1023/B:JOCM.0000025279.27084.39
44. Hassan RA, Rahman Bacterial contamination of computer keyboards and mouse. *Tikri, Jourual of Pure Science* 2014;19(5)
45. Hirsch EB, Raux BR, Lancaster JW, et al. Surface microbiology of the iPad tablet computer and the potential to serve as a fomite in both inpatient practice settings as well as outside of the hospital environment. *PLoS One* 2014;9(10):e111250. doi: 10.1371/journal.pone.0111250 [published Online First: 2014/11/02]

46. Hong D, Park S, Lee K, et al. Bacterial contamination of computer and hand hygiene compliance in the emergency department. *Hong Kong Journal of Emergency Medicine* 2012;19(6):387.
47. Jones R, Hutton A, Mariyaselvam M, et al. Keyboard cleanliness: A controlled study of the residual effect of chlorhexidine gluconate. *American journal of infection control* 2015;43(3):289-91. doi: 10.1016/j.ajic.2014.12.002
48. Jungnickel T, Von Jan U, Graf K, et al. Bugs! iPad-hygiene in healthcare. *Biomedizinische Technik* 2014;59:S1257-S60. doi: 10.1515/bmt-2014-5016
49. Karbasizade V, Sichani M, Parsafar S. Bacterial contamination of computer keyboards in hospitals in Isfahan in Iran. *International Journal of Biosciences (IJB)* 2014;4(1):320-24.
50. Keerasuntonpong A, Kesornsuk S, Trakulsomboon S, et al. Colonization of Nosocomial Pathogens on Computer Keyboards in Patient Care Areas. *Siriraj Medical Journal* 2017;57(9):380-81.
51. Khan A, Rao A, Reyes-Sacin C, et al. Use of portable electronic devices in a hospital setting and their potential for bacterial colonization. *American journal of infection control* 2015;43(3):286-8. doi: 10.1016/j.ajic.2014.11.013 [published Online First: 2015/01/06]
52. Kiedrowski LM, Perisetti A, Loock MH, et al. Disinfection of iPad to reduce contamination with Clostridium difficile and methicillin-resistant Staphylococcus aureus. *American journal of infection control* 2013;41(11):1136-7. doi: 10.1016/j.ajic.2013.01.030 [published Online First: 2013/05/11]
53. Link T, Kleiner C, Mancuso MP, et al. Determining high touch areas in the operating room with levels of contamination. *American journal of infection control* 2016;44(11):1350-55. doi: 10.1016/j.ajic.2016.03.013 [published Online First: 2016/11/05]
54. Lu PL, Siu LK, Chen TC, et al. Methicillin-resistant Staphylococcus aureus and Acinetobacter baumannii on computer interface surfaces of hospital wards and association with clinical isolates. *BMC infectious diseases* 2009;9:164. doi: 10.1186/1471-2334-9-164
55. Malta CP, Damasceno NN, Ribeiro RA, et al. Microbiological contamination in digital radiography: evaluation at the radiology clinic of an educational institution. *Acta odontologica latinoamericana : AOL* 2016;29(3):239-47. [published Online First: 2017/04/07]
56. Man GS, Olapoju M, Chadwick MV, et al. Bacterial contamination of ward-based computer terminals. The Journal of hospital infection. England2002:314-5.
57. Martin ET, Qin X, Baden H, et al. Randomized double-blind crossover trial of ultraviolet light-sanitized keyboards in a pediatric hospital. *American journal of infection control* 2011;39(5):433-35. doi: 10.1016/j.ajic.2010.10.016
58. Messina G, Ceriale E, Burgassi S, et al. Impact of a disinfecting technique on microbial contamination of computer keyboards and telephone handsets. *2* 2013 doi: http://www.sciedupress.com/journal/index.php/jha/article/view/2530
59. Messina G, Ceriale E, Lenzi D, et al. Environmental contaminants in hospital settings and progress in disinfecting techniques. *BioMed research international* 2013;2013:429780. doi: 10.1155/2013/429780 [published Online First: 2013/11/29]
60. Moore G, Muzslay M, Wilson AP. The type, level, and distribution of microorganisms within the ward environment: a zonal analysis of an intensive care unit and a gastrointestinal surgical ward. *Infection control and hospital epidemiology* 2013;34(5):500-6. doi: 10.1086/670219 [published Online First: 2013/04/11]
61. Morter S, Bennet G, Fish J, et al. Norovirus in the hospital setting: virus introduction and spread within the hospital environment. *The Journal of hospital infection* 2011;77(2):106-12. doi: 10.1016/j.jhin.2010.09.035 [published Online First: 2010/12/21]
62. Motta RH, Groppo FC, Bergamaschi Cde C, et al. Isolation and antimicrobial resistance of Staphylococcus aureus isolates in a dental clinic environment. *Infection control and hospital epidemiology* 2007;28(2):185-90. doi: 10.1086/510867 [published Online First: 2007/02/01]

63. Neely AN, Maley MP, Warden GD. Computer keyboards as reservoirs for Acinetobacter baumannii in a burn hospital. Clinical infectious diseases : an official publication of the Infectious Diseases Society of America. United States1999:1358-60.
64. Oguzkaya-Artan M, Baykan Z, Artan C, et al. Prevalence and risk factors for methicillin resistant Staphylococcus aureus carriage among emergency department workers and bacterial contamination on touch surfaces in Erciyes University Hospital, Kayseri, Turkey. *Afr Health Sci* 2015;15(4):1289-94. doi: 10.4314/ahs.v15i4.31 [published Online First: 2016/03/10]
65. Oie S, Yanagi C, Matsui H, et al. Contamination of environmental surfaces by Staphylococcus aureus in a dermatological ward and its preventive measures. *Biological and Pharmaceutical Bulletin* 2005;28(1):120-23. doi: 10.1248/bpb.28.120
66. Otter JA, Passaretti CL, French GL, et al. Low frequency of environmental contamination with methicillin-resistant Staphylococcus aureus in an inner city emergency department and a human immunodeficiency virus outpatient clinic. *American journal of infection control* 2011;39(2):151-3. doi: 10.1016/j.ajic.2010.05.022 [published Online First: 2010/10/05]
67. Patel S, Porter K, Sammons RL. Are computer keyboards a cross-infection risk in a dental clinic? *Journal of Infection Prevention* 2010;11(6):206-11. doi: 10.1177/1757177410384892
68. Phumisantiphong U, Diraphat P, Utrarachkij F, et al. Clonal spread of carbapenem resistant Acinetobacter baumannii in the patients and their environment at BMA Medical College and Vajira Hospital. *Journal of the Medical Association of Thailand = Chotmaihet thangphaet* 2009;92 Suppl 7:S173-80. [published Online First: 2010/03/18]
69. Pugliese A, Garcia AJ, Dobson W, et al. The prevalence of bacterial contamination of standard keyboards in an urban ED. *American Journal of Emergency Medicine* 2011;29(8):954-55. doi: 10.1016/j.ajem.2011.04.024
70. Rastogi S, Shah R, Perlman J, et al. Pattern of bacterial colonization in a new neonatal intensive care unit and its association with infections in infants. *American journal of infection control* 2012;40(6):512-5. doi: 10.1016/j.ajic.2012.02.016 [published Online First: 2012/08/03]
71. Reem RE, Van Balen J, Hoet AE, et al. Screening and characterization of Staphylococcus aureus from ophthalmology clinic surfaces: a proposed surveillance tool. *American journal of ophthalmology* 2014;157(4):781-87.e2. doi: 10.1016/j.ajo.2014.01.008 [published Online First: 2014/01/15]
72. Richard RD, Bowen TR. What Orthopaedic Operating Room Surfaces Are Contaminated With Bioburden? A Study Using the ATP Bioluminescence Assay. *Clin Orthop Relat Res* 2017;475(7):1819-24. doi: 10.1007/s11999-016-5221-5 [published Online First: 2017/01/05]
73. Rutala WA, White MS, Gergen MF, et al. Bacterial contamination of keyboards: efficacy and functional impact of disinfectants. *Infection control and hospital epidemiology* 2006;27(4):372-7. doi: 10.1086/503340 [published Online First: 2006/04/20]
74. Saito Y, Yasuhara H, Murakoshi S, et al. Time-dependent influence on assessment of contaminated environmental surfaces in operating rooms. *American journal of infection control* 2015;43(9):951-55. doi: 10.1016/j.ajic.2015.04.196
75. Schultz M, Gill J, Zubairi S, et al. Bacterial contamination of computer keyboards in a teaching hospital. *Infection control and hospital epidemiology* 2003;24(4):302-3. doi: 10.1086/502200 [published Online First: 2003/05/03]
76. Senok A, Garaween G, Raji A, et al. Genetic relatedness of clinical and environmental Acinetobacter baumanii isolates from an intensive care unit outbreak. *Journal of infection in developing countries* 2015;9(6):665-9. doi: 10.3855/jidc.6726 [published Online First: 2015/07/06]
77. Shaikh AA, Ely D, Cadnum JL, et al. Evaluation of a low-intensity ultraviolet-C radiation device for decontamination of computer keyboards. *American journal of infection control* 2016;44(6):705-7. doi: 10.1016/j.ajic.2015.11.025 [published Online First: 2016/01/20]

78. Smith SJ, Knouse MC, Wasser T. Prevalence of bacterial pathogens on physician handheld computers. *Journal of Clinical Outcomes Management* 2006;13(4):223-26.
79. Stambaugh RV, Elson L. Contaminated surfaces. *Dimensions of Dental Hygiene* 2009;7(6):(5p).
80. Sweeney CP, Dancer SJ. Can hospital computers be disinfected using a hand-held UV light source? The Journal of hospital infection. England2009:92-4.
81. Sykes A, Appleby M, Perry J, et al. An investigation of the microbiological contamination of ultrasound equipment. *British Journal of Infection Control* 2006;7(4):16-20. doi: 10.1177/14690446060070040501
82. Tan TY, Tan JS, Tay H, et al. Multidrug-resistant organisms in a routine ward environment: differential propensity for environmental dissemination and implications for infection control. *J Med Microbiol* 2013;62(Pt 5):766-72. doi: 10.1099/jmm.0.052860-0 [published Online First: 2013/02/09]
83. Trochesset DA, Walker SG. Isolation of Staphylococcus aureus from environmental surfaces in an academic dental clinic. *Journal of the American Dental Association (1939)* 2012;143(2):164-9. [published Online First: 2012/02/03]
84. Waghorn DJ, Wan WY, Greaves C, et al. Contamination of computer keyboards in clinical areas: potential reservoir for nosocomial spread of organisms. *British Journal of Infection Control* 2005;6(3):(3p).
85. Westerway SC, Basseal JM, Brockway A, et al. Potential Infection Control Risks Associated with Ultrasound Equipment - A Bacterial Perspective. *Ultrasound in medicine & biology* 2017;43(2):421-26. doi: 10.1016/j.ultrasmedbio.2016.09.004 [published Online First: 2017/03/28]
86. Wilson AP, Hayman S, Folan P, et al. Computer keyboards and the spread of MRSA. The Journal of hospital infection. England2006:390-2.
87. Wilson APR, Ostro P, Magnussen M, et al. Laboratory and in-use assessment of methicillin-resistant Staphylococcus aureus contamination of ergonomic computer keyboards for ward use. *American journal of infection control* 2008;36(10):e19-e25. doi: 10.1016/j.ajic.2008.09.001
88. Wilson AP, Smyth D, Moore G, et al. The impact of enhanced cleaning within the intensive care unit on contamination of the near-patient environment with hospital pathogens: a randomized crossover study in critical care units in two hospitals. *Critical care medicine* 2011;39(4):651-8. doi: 10.1097/CCM.0b013e318206bc66 [published Online First: 2011/01/19]
89. Xu H, Chen B, Ni X, et al. Computer keyboard and mouse: An intervention study on methicillin-resistant staphylococcus aureus decontamination in 4 intensive care units. *Journal of critical care* 2017;37:266-67. doi: 10.1016/j.jcrc.2016.09.021
90. Yun HC, Kreft RE, Castillo MA, et al. Comparison of PCR/electron spray ionization-time-of-flight-mass spectrometry versus traditional clinical microbiology for active surveillance of organisms contaminating high-use surfaces in a burn intensive care unit, an orthopedic ward and healthcare workers. *BMC infectious diseases* 2012;12:252. doi: 10.1186/1471-2334-12-252 [published Online First: 2012/10/12]
91. Russotto V, Cortegiani A, Raineri SM, Giarratano A. Bacterial contamination of inanimate surfaces and equipment in the intensive care unit. *J Intensive Care* 2015;3:54. doi: 10.1186/s40560-015-0120-5
92. Rusin P, Maxwell S, Gerba C. Comparative surface-to-hand and fingertip-to-mouth transfer efficiency of gram-positive bacteria, gram-negative bacteria, and phage. *Journal of applied microbiology* 2002;93(4):585-92. [published Online First: 2002/09/18]
93. Stiefel U, Cadnum JL, Eckstein BC, et al. Contamination of hands with methicillin-resistant Staphylococcus aureus after contact with environmental surfaces and after contact with the skin

of colonized patients. *Infection control and hospital epidemiology* 2011;32(2):185-7. doi: 10.1086/657944 [published Online First: 2011/04/05]
94. Boyce JM, Potter-Bynoe G, Chenevert C, et al. Environmental contamination due to methicillin-resistant Staphylococcus aureus: possible infection control implications. *Infection control and hospital epidemiology* 1997;18(9):622-7. [published Online First: 1997/10/06]
95. Kramer A, Schwebke I, Kampf G. How long do nosocomial pathogens persist on inanimate surfaces? A systematic review. *BMC infectious diseases* 2006;6:130. doi: 10.1186/1471-2334-6-130 [published Online First: 2006/08/18]
96. Dancer SJ. Controlling Hospital-Acquired Infection: Focus on the Role of the Environment and New Technologies for Decontamination. *Clin Microbiol Rev* 2014;27(4):665-90. doi: 10.1128/cmr.00020-14
97. Otter JA, Yezli S, Salkeld JA, et al. Evidence that contaminated surfaces contribute to the transmission of hospital pathogens and an overview of strategies to address contaminated surfaces in hospital settings. *American journal of infection control* 2013;41(5 Suppl):S6-11. doi: 10.1016/j.ajic.2012.12.004 [published Online First: 2013/05/03]
98. Donskey CJ. Does improving surface cleaning and disinfection reduce health care-associated infections? *American journal of infection control* 2013;41(5 Suppl):S12-9. doi: 10.1016/j.ajic.2012.12.010 [published Online First: 2013/03/08]
99. Erasmus V, Daha TJ, Brug H, et al. Systematic review of studies on compliance with hand hygiene guidelines in hospital care. *Infection control and hospital epidemiology* 2010;31(3):283-94. doi: 10.1086/650451 [published Online First: 2010/01/22]
100. Kingston L, O'Connell NH, Dunne CP. Hand hygiene-related clinical trials reported since 2010: a systematic review. *The Journal of hospital infection* 2016;92(4):309-20. doi: 10.1016/j.jhin.2015.11.012 [published Online First: 2016/02/09]
101. Dettenkofer M, Block C. Hospital disinfection: efficacy and safety issues. *Curr Opin Infect Dis* 2005;18(4):320-5. [published Online First: 2005/06/30]
102. Rutala WA, Weber DJ. Are room decontamination units needed to prevent transmission of environmental pathogens? *Infection control and hospital epidemiology* 2011;32(8):743-7. doi: 10.1086/661226 [published Online First: 2011/07/20]
103. Boyce JM. Modern technologies for improving cleaning and disinfection of environmental surfaces in hospitals. *Antimicrob Resist Infect Control* 2016;5:10. doi: 10.1186/s13756-016-0111-x [published Online First: 2016/04/14]
104. Sehulster L, Chinn RY, Arduino M, et al. Guidelines for environmental infection control in health-care facilities. *Morbidity and mortality weekly report recommendations and reports RR* 2003;52(10)
105. Ejemot-Nwadiaro RI, Ehiri JE, Arikpo D, et al. Hand washing promotion for preventing diarrhoea. *The Cochrane database of systematic reviews* 2015(9):Cd004265. doi: 10.1002/14651858.CD004265.pub3 [published Online First: 2015/09/09]
106. Falagas ME, Thomaidis PC, Kotsantis IK, et al. Airborne hydrogen peroxide for disinfection of the hospital environment and infection control: a systematic review. *The Journal of hospital infection* 2011;78(3):171-7. doi: 10.1016/j.jhin.2010.12.006 [published Online First: 2011/03/12]
107. Murphy CR, Eells SJ, Quan V, et al. Methicillin-resistant Staphylococcus aureus burden in nursing homes associated with environmental contamination of common areas. *J Am Geriatr Soc* 2012;60(6):1012-8. doi: 10.1111/j.1532-5415.2012.03978.x [published Online First: 2012/06/08]

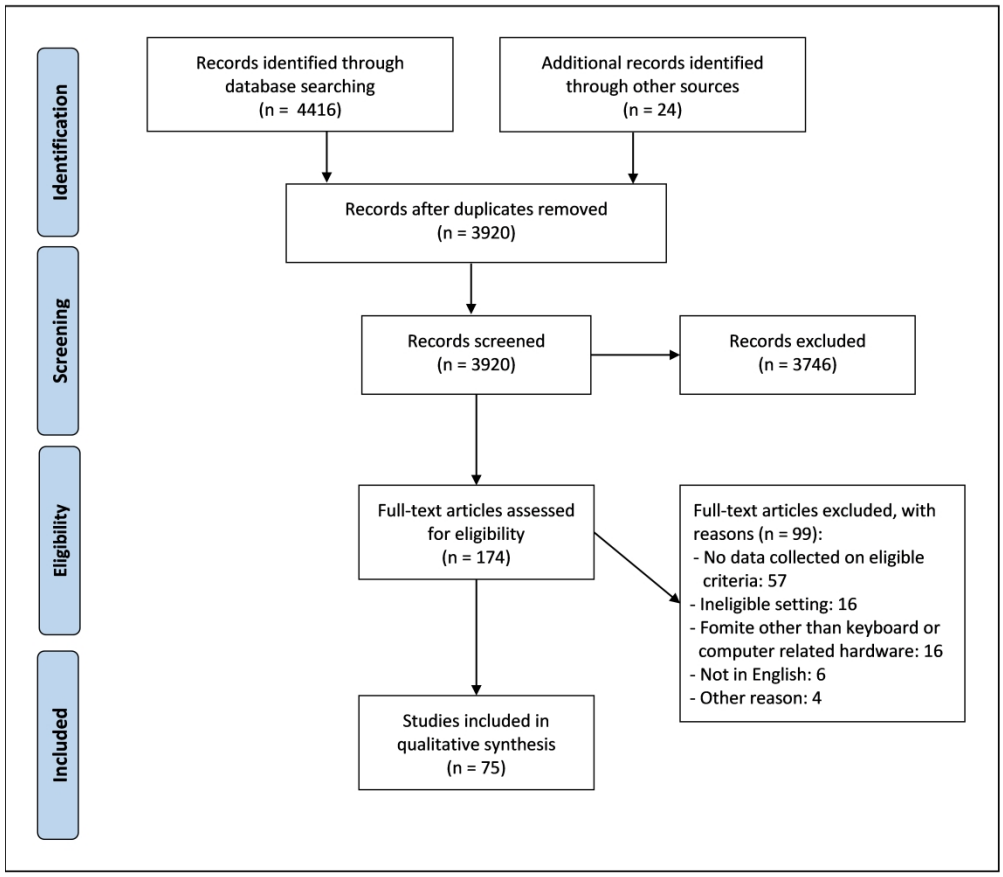


Figure 1 Flow Diagram of Study Selection

405x372mm (300 x 300 DPI)

# PRISMA 2009 Checklist

| Section/topic | # | Checklist item | Reported on page # |
|---|---|---|---|
| **TITLE** | | | |
| Title | 1 | Identify the report as a systematic review, meta-analysis, or both. | 1 |
| **ABSTRACT** | | | |
| Structured summary | 2 | Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number. | 2-3 |
| **INTRODUCTION** | | | |
| Rationale | 3 | Describe the rationale for the review in the context of what is already known. | 4 |
| Objectives | 4 | Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS). | 4-5 |
| **METHODS** | | | |
| Protocol and registration | 5 | Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number. | N/A |
| Eligibility criteria | 6 | Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale. | 5-6 |
| Information sources | 7 | Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched. | 5 |
| Search | 8 | Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated. | Suppl. File 2 |
| Study selection | 9 | State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis). | 5-6 |
| Data collection process | 10 | Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators. | 6-7 |
| Data items | 11 | List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made. | 6 |
| Risk of bias in individual studies | 12 | Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis. | 7 |
| Summary measures | 13 | State the principal summary measures (e.g., risk ratio, difference in means). | 7 |
| Synthesis of results | 14 | Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., $I^2$) for each meta-analysis. | 7 |

# PRISMA 2009 Checklist



| Section/topic | # | Checklist item | Reported on page # |
|---|---|---|---|
| Risk of bias across studies | 15 | Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies). | 7 |
| Additional analyses | 16 | Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified. | N/A |
| **RESULTS** | | | |
| Study selection | 17 | Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram. | 8 |
| Study characteristics | 18 | For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations. | Pp 8-9; Suppl. File 3 |
| Risk of bias within studies | 19 | Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12). | 15-16, Suppl. File 10 |
| Results of individual studies | 20 | For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot. | Pp 9-15; Table 1-2; Suppl. Files 4-9 |
| Synthesis of results | 21 | Present results of each meta-analysis done, including confidence intervals and measures of consistency. | N/A |
| Risk of bias across studies | 22 | Present results of any assessment of risk of bias across studies (see Item 15). | 15-16 |
| Additional analysis | 23 | Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]). | N/A |
| **DISCUSSION** | | | |
| Summary of evidence | 24 | Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers). | 16-19 |
| Limitations | 25 | Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias). | 18 |
| Conclusions | 26 | Provide a general interpretation of the results in the context of other evidence, and implications for future research. | 17, 18-19 |
| **FUNDING** | | | |
| Funding | 27 | Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review. | 20 |

*From:* Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097 

## Supplementary File 2: Example of search terms used

('cross infection'/exp OR 'cross infection':ti OR 'infection control'/exp OR 'disinfection'/exp OR disinfect*:ti OR 'medical device contamination'/exp OR 'disease transmission'/exp OR 'bacterial transmission'/exp OR 'disease carrier'/exp OR 'bacterial count'/exp OR 'microbiology'/exp OR 'antiinfective agent'/exp OR 'bacterial load'/exp OR 'bacterium identification'/exp OR 'bacterium contamination':ti OR 'microbial contamination':ti OR 'fungal contamination'/exp OR 'fungal detection'/exp OR contaminat*:ti OR decontaminat*:ti OR 'viral contamination':ti OR 'virus load'/exp OR 'ultraviolet radiation'/exp OR 'uv light':ab,ti OR 'ultraviolet light*':ab,ti OR 'uv lamp*':ab,ti OR 'ultraviolet lamp*':ab,ti OR 'waterproof keyboard*':ab,ti OR 'silicone cover*':ab,ti OR 'wipeable':ab,ti OR 'washable':ab,ti OR 'sanitiz*':ab,ti OR 'sanitis*':ab,ti OR 'steriliz*':ab,ti OR 'sterilis*':ab,ti OR 'swab*':ab,ti OR 'Vioguard' OR 'Seal Shield' OR 'Medigenic' OR 'Steridesign' OR 'SteriHood' OR 'Clinell' OR 'UV Angel' OR 'Esterline' OR 'hospital infection*':ab,ti OR 'HAI':ab,ti OR 'healthcare acquired infection*':ab,ti)

PLUS

('computer'/de OR 'computer mouse'/de OR 'keyboard'/de OR 'personal computer'/de OR 'personal digital assistant'/de OR keyboard*:ab,ti OR ipad:ab,ti OR ipads:ab,ti OR 'computer mouse':ab,ti OR 'computer mice':ab,ti OR 'mobile device*':ab,ti OR 'trackpad*':ab,ti OR 'mobile communication device*':ab,ti OR laptop:ab,ti OR laptops:ab,ti OR 'tablet computer*':ab,ti OR 'handheld computer*':ab,ti OR 'touch screen*':ab,ti OR 'touch-screen*':ab,ti)

## Supplementary File 3: Key characteristics of included studies

| AUTHOR, YEAR | SETTING | STUDY DESIGN | SAMPLE SIZE* | MICROBIOLOGICAL SAMPLING | OUTCOME MEASURE(S) | INTERVENTION DESCRIPTION (IF ANY) |
|---|---|---|---|---|---|---|
| **ALBRECHT 2013** | 10 clinical wards, Germany | Prospective comparative analysis | 10 iPads | Culture media with contact plates taken from 13 contact points on the iPad (front and back) | Total bacterial load | Isopropanol wipes using the 6-step disinfection process guided by the deBac-app. Devices in control arm cleaned with a cloth, without any liquid cleaning agents, as recommended in the iPad manufacturer instructions. |
| **AL-HAMAD 2008** | Nurse station areas in a hospital UK | Pre/Post | Unknown number of keyboards | Variety of hand-touch surfaces randomly sampled before and immediately after cleaning, prior to admission of a new patient. Surfaces in the common nurse station areas, where cleaning policy was not strictly followed, sampled randomly on two different occasions. Wards sampled 4 times: twice before cleaning and twice after. A subset of surfaces were sampled to determine the total aerobic count. | Total aerobic count (CFU) | |
| **ALI 2015** | Teaching hospital in UK | Cross Sectional | Unknown number of keyboards | Sampled by using either a contact plate or by wiping the entire test area (in a left-to-right motion, followed by wiping at 45° and 90° angles; the process was repeated 3 times) using a 25-cm2 sponge swab pre-moistened with neutralizing solution | Detection of C. diff | |
| **ANASTASIADES 2009** | ICUs at Academic Hospital South Africa | Repeated cross sectional, 2x | 14 keyboards and 14 mice | Moistened sterile swabs taken by student researchers trained by experienced medical technologist, taken at baseline and again 6 months later because initial sampling detected unexpectedly low S. aureus rates | Detection of CNS, Gram-positive bacilli, micrococci, fungi and S. aureus | |
| **BURES 2000** | ICU, USA | Repeated cross sectional, 2x/week for 2 months | 10 keyboards | Moistened swab from letter keys, space bar and enter key taken over 8 collection periods (2 nonconsecutive days of 2 nonconsecutive weeks for 2 months) | Total bacterial load | |
| **CATANO 2012** | Tertiary hospital, Colombia | Cross Sectional | 30 keyboards | Surfaces randomly sampled with moistened swabs during weekdays. | Total bacterial load | |

| AUTHOR, YEAR | SETTING | STUDY DESIGN | SAMPLE SIZE* | MICROBIOLOGICAL SAMPLING | OUTCOME MEASURE(S) | INTERVENTION DESCRIPTION (IF ANY) |
|---|---|---|---|---|---|---|
| **CHOI 2014** | Endoscopy rooms of 2 tertiary hospitals Korea | Cross sectional | Unknown number of keyboards | Moistened cotton tipped swabs were taken from all surfaces after endoscopy was performed, one time each in the morning and afternoon | Total bacterial load (CFU) | |
| **CIRAGIL 2006** | Patient and exam rooms, OR, offices, non-clinical areas, Turkey | Cross Sectional | 56 keyboards in clinical areas | Moistened swabs collected from entire surface of keyboard | Total bacterial load | |
| **CODISH 2015** | Internal medicine wards and ICU, Israel | Cluster RCT | 81 keyboards + 81 mice | Sampling done with Eswab. Culture specimens taken from keyboards and mice prior to the intervention and 2 weeks after intervention began. | Total bacterial load | MEDIWIPES (alcohol based) vs. TriGene (quaternary ammonium based). Each device decontaminated 3 times a day. |
| **CORDEIRO 2015** | ICU Brazil | Pre-post | 6 keyboards | Sterile swabs taken by the researchers, 2 swabs from each device (once before applying the cleaning/ disinfection product and another one right after the equipment was dried, without a pre-established waiting time) | Total bacterial load | Computer keyboards were cleaned on a daily basis with a brush for removing dust. |
| **DANCER 2008** | 2 acute surgical wards at a teaching hospital UK | Repeated cross sectional, 1x week for 6 months per ward | 2 keyboards, 1 per ward | Dip slides were used for sampling by an unspecified person. Screening was conducted in each ward for a 6 month period, first on ward B, then 6 months on ward A. Sampling done after routine cleaning and taken once weekly. | Hygienic failure was considered a site with ACC greater than 2.5 CFU/cm2 or any site demonstrating the presence of MSSA or MRSA | |
| **DANCER 2009** | 2 Surgical wards with endemic MRSA, UK | Prospective Cross-over | 2 keyboards | Dip slides used for sampling keyboards | Hygienic failure was considered a site with ACC greater than 2.5 cfu/cm2 or any site demonstrating the presence of MSSA or MRSA | Enhanced cleaning: additional cleaner added to ward and trained to clean hand-touch sites 1-3 times per day depending on location Monday to Friday. |

| AUTHOR, YEAR | SETTING | STUDY DESIGN | SAMPLE SIZE* | MICROBIOLOGICAL SAMPLING | OUTCOME MEASURE(S) | INTERVENTION DESCRIPTION (IF ANY) |
|---|---|---|---|---|---|---|
| **DE GROOD 2012** | Medical, surgical, ICU units in 4 urban hospitals, Canada | Cross sectional + nested Pre/Post | 240 keyboards | Conventional keyboards cultured 3 times using moistened sterile applicators: 1) in the morning pre cleaning, 2) approximately 2 hours following the initial swabs (after routine cleaning), and 3) post cleaning with a "CaviWipe".<br>Later, 10 "Cleankeys" keyboards were placed on hospital ward in selected high usage areas of a Medical Centre and cultured pre-, after 2 hours, and post-cleaning using methods as above. | Total bacterial load | "CaviWipes" (a quaternary ammonium compound) with isopropanol) |
| **DEVINE 2001** | Nurse stations in 2 district hospitals' acute medical and surgical wards, UK | Cross Sectional | 25 terminals (keyboard, mouse, mouse pad) | Swabs taken from entire keyboards, mouse, and mouse mat by same individual | Detection of MRSA | |
| **DUMFORD 2009** | Patient rooms, physician and nurse work areas, portable equipment, 3 wards, USA | Pre/Post | 32 computers in initial survey, 25 computers and 1 mouse in follow up survey | Moistened swabs taken from entire keyboard surface | Detection of C. diff | Disinfection with bleach |
| **DUSZAK 2014** | outpatient radiology workstations in 2 hospitals, USA | Cross Sectional + Pre/Post at 2 hospitals | 7 mice | Samples taken using direct contact with sterile plates | Total bacterial load | "Chlorascrub" pads (chlorhexidine gluconate and isopropyl alcohol) |
| **ENGELHART 2008** | Non-clinical and clinical areas of a University Hospital, Germany | Cross Sectional | 77 computer terminals in clinical areas (keyboard, mouse) | Samples taken by direct contact using Rodac plates from the enter key, space bar, and mouse by trained investigator | Total bacterial load | |

| AUTHOR, YEAR | SETTING | STUDY DESIGN | SAMPLE SIZE* | MICROBIOLOGICAL SAMPLING | OUTCOME MEASURE(S) | INTERVENTION DESCRIPTION (IF ANY) |
|---|---|---|---|---|---|---|
| **FAIRES 2012** | 3 community hospitals, Canada | Repeated cross sectional at 4 time points | Unknown number of keyboards | Samples taken with dry electrostatic cloths, once per week for 4 consecutive weeks, prior to daily cleaning | Detection of MRSA or C. Diff | |
| **FAIRES 2013** | 2 Medical wards and 1 surgical ward Canada | Repeated cross sectional, 6 times over 15 weeks | Unknown number of keyboards | Sterile electrostatic cloths were used for sampling, done by the investigator. Half the surface with one cloth and the other half with another. Sampling was conducted once a week for 3 consecutive weeks during weeks 1–3 and weeks 13–15, prior to cleaning. | Detection of MRSA or C. Diff | |
| **FELLOWES 2006** | General clinical hospital areas, UK | Cross Sectional | 44 keyboards | Swabs taken from enter key and spacebar | Detection of MRSA or MSSA | |
| **FARIAS 2017** | Renal Transplant ward Portugal | Repeated cross sectional, over 3 months | 1 keyboard | Samples were always collected at the end of the morning and during lunch time, after the medical visits and treatments, collected over a 3 month period. Swabs were used to sample an area of 10x10 cm of each surface. | Total bacterial load | |
| **FUKADA 2008** | OR, ICU, consulting room, outpatient reception area, Japan | Pre/Post | Unknown number of keyboards | Moistened swabs taken from all keys before and after cleaning | Total bacterial load | Cotton cellulose sheet dampened with ethyl alcohol |
| **GERBA 2016** | Hospital, USA | Cross sectional | 17 computer touch screens | Samples taken from computer touch screens over course of one day using a sterile sponge stick | Coliform bacterial growth | |
| **GOSTINE 2016** | ICU, USA | Pre/Post with various exposure frequencies | 40 keyboards | Samples collected at 6AM, before cleaning. eSwab liquid based collection and transport system kit used for sampling | Total bacterial load | UV Angel Desktop lamps, set to 3-, 5-, 6-, and 10-minute cycle lengths |
| **GRABSCH 2012** | Hospital, Australia | Pre/Post | Unknown number of keyboards | Moistened swabs taken monthly during program periods B1 and B2 (not performed regularly during period A) | Detection of VRE | Hospital wide program including 'Bleach-Clean': replaced surface cleaners with sodium hypochlorite solution plus Chloradet detergent; install cleaner dispensing stations, employment of cleaning |

| AUTHOR, YEAR | SETTING | STUDY DESIGN | SAMPLE SIZE* | MICROBIOLOGICAL SAMPLING | OUTCOME MEASURE(S) | INTERVENTION DESCRIPTION (IF ANY) |
|---|---|---|---|---|---|---|
| | | | | | | supervisors and training program for cleaning staff, performance appraisals, modify protocols for managing VRE-colonized patients, thrice annual schedule of "super clean disinfection" |
| **GRAY 2007** | Emergency Northern Ireland | Repeated cross sectional, 3x over one year | 7 computer mice | Sampling was performed on three occasions over a 1 year period and performed unannounced by one of the authors. Moistened bacteriology swab used on the palm rest and left click button. A swab was also taken from the plastic edging surrounding the keyboard as a control | Total bacterial load | |
| **HARDY 2014** | All wards in 3 hospitals UK | Repeated cross sectional, over a 22 month period | Unknown number of keyboards and computers on wheels | Once a period of increased incidence of C. diff was identified, all wards had ATP sampling undertaken on a weekly basis in the afternoon by an infection control nurse. | RLU levels over 1,000 considered to be unacceptable (red code). A result between 500 and 1,000 RLU was given an intermediate rating or amber code | |
| **HARTMANN 2004** | ICU, Germany | Repeated cross sectional over 3 months | Unknown number of keyboards and mice | Keyboards and mice sampled with a moistened swab during 2 periods of 3 months each on 8 nonconsecutive days. | Potentially pathogenic microorganisms (2+ CFU) | |
| **HASSAN 2014** | Staff rooms, computer labs, internet centers in a teaching hospital, Iraq | Cross Sectional | 150 keyboards and 100 mice | Sterile swabs taken of keyboards and mice | Total bacterial load | |
| **HIRSCH 2014** | University department of pharmacy | Cross Sectional | 30 iPads | 5 swabs taken once (4 wet and 1 dry), 6 months following iPad distribution | Total bacterial load | |

| AUTHOR, YEAR | SETTING | STUDY DESIGN | SAMPLE SIZE* | MICROBIOLOGICAL SAMPLING | OUTCOME MEASURE(S) | INTERVENTION DESCRIPTION (IF ANY) |
|---|---|---|---|---|---|---|
| | practice, USA | | | | | |
| **HONG 2012** | Emergency dept of 3 teaching hospitals South Korea | Cross sectional | 112 computer items (56 keyboards and 56 mice) | A single sterile moistened swab was wiped over the keyboard and electronic mouse surfaces by one of the authors wearing sterile gloves. Keyboards were sampled by moving the sterile swab over the all keys over 60 seconds. The areas tested on each mouse were the palm rest, left and right click buttons of the mouse, and a standard 6 $cm^2$ area was swabbed. | Total bacterial load | |
| **JONES 2015** | ICU, UK | Controlled Trial | 8 keyboards for controlled study + 24 keyboards for intervention | Daily samples obtained using moistened swabs from entire keyboard and all keys at 4-6h and 24h of clinical use, daily for 16 days. | Total bacterial load | CHG spray (2% chlorhexidine gluconate-70% isopropyl alcohol) vs. TF spray (chlorine dioxide-based) |
| **JUNGNICKEL 2014** | Several clinical departments and wards at a Medical School, Germany | Pre/Post | 5 iPads | Sampling using contact plates done before and after disinfection intervention | Total bacterial load | Isopropanol wipes using the 6-step disinfection process guided by the deBac-app. |
| **KARBASIZADE 2014** | Medical wards of various hospitals Iran | Cross sectional | 65 keyboards | A sterile swab which had been dampened by Trypticase soy agar, was applied on the entire keyboard. | Total bacterial load | |
| **KEERASUNTO-NGPONG 207** | General medical wards, ICU Thailand | Cross sectional | 26 keyboards | A sterile cotton swab, moistened with sterile normal saline solution, was rolled over the F and J keys, the number 4 and 5 keys, and the enter key and space bar | Total bacterial load | |
| **KHAN 2015** | 2 large academic institution medical centers, USA | Cross Sectional | 106 portable electronic devices (93 were iPads/ tablet) | Moistened swabs taken of house officers' and attending physicians' carrying devices. Separate swabs were used for the screen, cover, and keyboard if applicable. | Total bacterial load | |
| **KIEDROWSKI 2013** | Hospital, USA | Cross Sectional | 20 iPads | iPad screens swabbed. | Detection of C.diff, MRSA | |

| AUTHOR, YEAR | SETTING | STUDY DESIGN | SAMPLE SIZE* | MICROBIOLOGICAL SAMPLING | OUTCOME MEASURE(S) | INTERVENTION DESCRIPTION (IF ANY) |
|---|---|---|---|---|---|---|
| **LINK 2016** | OR, USA | Cross sectional with control | Unknown number of keyboards and mice | Samples obtained over a 3 week period, pre- and post-procedure and before cleaning. Samples taken with a sponge stick. | Total bacterial load | |
| **LU 2009** | All ward stations of university hospital, Taiwan | Cross Sectional | 282 stations (keyboard and mouse) | Moistened swabs taken from keyboards and mice | S. aureus, Pseudomonas sp, and Acinetobacter sp | |
| **MALTA 2016** | Dental radiology clinic at public educational institution, Brazil | Repeated cross sectional at 2 time points | Unknown number of keyboard and mice on radiological equipment | Sterile moistened swab samples collected over 3 nonconsecutive random days at 2 different times: in the morning, before attending patients, and at end of day after appointment hours and before cleaning and disinfection procedures. | Total bacterial load | |
| **MAN 2002** | Nurse stations, patient bed bays in multiple wards, UK | Cross Sectional | 85 keyboards + 80 mice + 44 mouse pads | Sterile moist swabs taken of the entire surface of every key and crevice of each keyboard, mouse, and mouse pad | Total bacterial load | |
| **MARTIN 2011** | ICU and ER in pediatric hospital, USA | Randomized double blind cross-over trial | 72 terminals (keyboards/ mouse/pad): 24 Vioguard keyboards, 24 control keyboards, 24 existing keyboards | Moistened swabs taken from the mouse pad, mouse buttons, and the ''F,'' ''M,'' ''Enter,'' and ''Space'' keys, sampled with a single swab | Total bacterial load | Keyboards with "Vioguard" UV light irradiation with identical control keyboards not exposed to UV light irradiation. |
| **MESSINA 2013 (A)** | 4 different medical units, Italy | Pre/Post | 27 keyboards | A first swab taken from one half of the surfaces before cleaning with the putty and a second sample from other half of surfaces after cleaning. Sides were alternated. | Total bacteria count of: Staphylococcus spp, Pseudomonas spp, E. coli, total coliform bacteria, C.diff, Acinetobacter spp, | A putty cleaning compound (ethanol 29%) with malleable-elastic consistency, designed to adhere to surfaces, remove dirt and disinfect |

| AUTHOR, YEAR | SETTING | STUDY DESIGN | SAMPLE SIZE* | MICROBIOLOGICAL SAMPLING | OUTCOME MEASURE(S) | INTERVENTION DESCRIPTION (IF ANY) |
|---|---|---|---|---|---|---|
| **MESSINA 2013 (B)** | Various units within 3 hospitals, Italy | Pre/Post | 50 keyboards | A first swab taken from one half of each keyboard before cleaning, and a second sample from other half after cleaning. Samples obtained by swabbing almost all the keys and also going between/under the keys with cotton sterile pads. | Total bacterial load | A putty cleaning compound (ethanol 29%) with malleable-elastic consistency, designed to adhere to surfaces, removing dirt and disinfect |
| **MOORE 2013** | ICU and GI surgical wards, UK | Repeated cross sectional over 17 weeks | Unknown number of keyboards | Sampling conducted on variety of surfaces using direct contact methods (blood agar contact plates). 33 samples taken over 17 weeks. | Aerobic colony counts | |
| **MORTER 2011** | Ward rooms, UK | Cross sectional Post-intervention | 10 keyboards + 8 mice | All surfaces in rooms where NoV infected patients stayed were cleaned with Actichlor solution. Then, moistened swabs taken from variety of surfaces, including keyboards/mice. Two wards on which NoV was detected on environmental surfaces after cleaning were subjected to second clinical clean and tested again. | Detection of Norovirus | Actichlor plus solution |
| **MOTTA 2007** | Undergrad dental school clinic, Brazil | Repeated cross sectional at 1/mo over 1 year | 4 keyboards | 3 samples (moistened swabs) taken bimonthly during a 1 year period - before, during, and after clinical procedure hours. | Detection of S. aureus | |
| **NEELY 1999** | Burn Hospital, USA | Pre/Post | Unknown number of keyboards | Not specified | Detection of Acinetobacter species | Enhanced cleaning policy: All personnel required to wear gloves before using computer and removed before leaving the room. Also, housekeeping staff given a defined daily cleaning procedure for cleaning the plastic keyboard covers |
| **OGUZKAYA-ARTAN 2015** | ER, Turkey | Cross Sectional | 14 keyboards + 5 desktop surfaces | Swab samples taken from keyboards | Detection of S. aureus | |
| **OIE 2005** | Dermatology ward, Japan | Cross Sectional | 1 keyboard | Samples taken of entire surface of keyboards with moistened sterile gauze swab. For the items showing contamination by 100 CFU or more MRSA or MSSA in at least one of the repeated examinations, half the area of each | Detection of S. aureus | |

| AUTHOR, YEAR | SETTING | STUDY DESIGN | SAMPLE SIZE* | MICROBIOLOGICAL SAMPLING | OUTCOME MEASURE(S) | INTERVENTION DESCRIPTION (IF ANY) |
|---|---|---|---|---|---|---|
| | | | | surface was examined for S. aureus contamination. Subsequently, entire surface disinfected and the other half area was examined for contamination. | | |
| **OTTER 2011** | Hospital emergency department and an outpatient HIV clinic US | Cross sectional | Unknown number of keyboards | Cotton-tipped moistened sterile swabs used. Surfaces swabbed 100 $cm^2$ areas by standardized swabbing in two directions at right angles. | Detection of MRSA | |
| **PATEL 2010** | 2 student study areas and 2 patient clinics in a dental hospital, UK | Cross sectional + nested Pre/Post | 8 keyboards | Keyboards swabbed using swab moistened with sterile distilled water by a single investigator. Keyboards sampled 3 times each: by running the tip of the swab from left to right over the entire length covering the tops of all the keys and then turning the swab and returning over the same surface.<br>Later, 2 keyboards in clinical and study areas disinfected twice a day using isopropanol wipes. After 5 days, they were swabbed again. | Total bacterial load | 70% isopropanol wipes vs. Virkon (dipotassium peroxodisulphate) |
| **PHUMISANTIPHONG 2009** | Hospital patient rooms and nurse station, Thailand | Cross Sectional | 30 computer terminals (keyboards/ mice) | Not specified | Detection of CRAB | |
| **PUGLIESE 2011** | ER, USA | Cross Sectional | 72 keyboards | Keyboards sampled by moist swab, taken from all keys except the function keys | Total bacterial load | |
| **RASTOGI 2012** | NICU, USA | Repeated cross sectional, biweekly for 1 yr | 3 keyboards | Samples taken using moistened swabs biweekly for 1 year by a culture swab and transport company | Total bacterial load | |
| **REEM 2014** | Exam and imaging rooms, common areas in an ophthalmolo | Repeated cross sectional, quarterly for 1 year | 16 keyboards | Sampling conducted on quarterly basis for 1 year. Collected at the end of day, prior to daily cleaning by a trained personnel wearing clean clothing covers and gloves. (Unclear if keyboard sampling done using electrostatic cloth or moistened swabs.) | Detection of MRSA/MSSA isolates | |

| AUTHOR, YEAR | SETTING | STUDY DESIGN | SAMPLE SIZE* | MICROBIOLOGICAL SAMPLING | OUTCOME MEASURE(S) | INTERVENTION DESCRIPTION (IF ANY) |
|---|---|---|---|---|---|---|
| | gy clinic, USA | | | | | |
| **RICHARD 2017** | Orthopedic OR, USA | Cross Sectional | 6 keyboards | On a given day, surfaces in 6 different orthopedic surgery operating rooms tested before surgery with ATP bioluminescence swabs | Total bacterial load, measured in RLUs | |
| **RUTALA 2006** | Burn ICU, cardiothoracic ICU, nursing units, USA | Cross Sectional | 25 keyboards | Single sterile swab wiped over entire surface of keyboards | Total bacterial load | |
| **SAITO 2015** | Six ORs, Japan | Cross Sectional | 12 keyboards and 6 touch screens | Contamination assessed using an ATP test and bacterial culture using moistened swabs | mean ATP value (log10 RLU)<br>for microbial count: log10 CFU | |
| **SCHULTZ 2003** | VA hospital: areas close to patients in acute care, ambulatory care, and long term care, USA | Cross Sectional | 100 keyboards | During 4 week period, samples taken using moistened swabs from all over keyboard surfaces | Total bacterial load | |
| **SENOK 2015** | ICU nursing stations, Saudi Arabia | Cross Sectional | Unknown number of keyboards and mice | ATM moistened swabs taken of environmental surfaces during an outbreak of multi-drug resistant A. baumannii (MRAB) | Detection of A. baumannii isolates | |
| **SHAIKH 2016** | Unknown hospital setting, USA | Pre/Post with various exposure frequencies | 25 keyboards in current use but unclear setting | One half of the keyboard sampled with a moistened swab before use of the UV device, and the other half sampled after decontamination. | Total bacterial load | UV Angel system |
| **SMITH 2006** | Medical, surgical, family practice programs of tertiary hospital, USA | Pre/Post | 60 notebooks (keys and grips) | Samples taken over approximately 8 days over several-month period. Sampling done with moistened swab wiped over space key and enter key.<br>An identical protocol used for 17 devices looking specifically for C. difficile but did not test for spores. | Total bacterial load | Clorox disinfecting wipes |

| AUTHOR, YEAR | SETTING | STUDY DESIGN | SAMPLE SIZE* | MICROBIOLOGICAL SAMPLING | OUTCOME MEASURE(S) | INTERVENTION DESCRIPTION (IF ANY) |
|---|---|---|---|---|---|---|
| | | | | For general comparison, swabs were taken from 23 hospital hallway desktop computers on all patient care floors and units. Following the culture collection, medical residents were instructed to disinfect their notebooks 3 times per day with Clorox disinfecting wipes. Three days after the protocol was introduced, the devices were randomly swabbed again. | | |
| **STAMBAUGH 2009** | Dental office, USA | Pre/Post with stratified groups | 88 keyboards or mice | Keyboards/mouse devices, which had never been cleansed or disinfected, sampled with a single sterile moistened swab over the entire keyboard and mouse. Then, keyboards were divided in 3 groups and evaluated for contamination over a period of 4 months. | Detection of Multidrug-resistant organisms | Disinfectant wipes (ammonium chloride and isopropyl alcohol) |
| **SWEENEY 2009** | Various clinical wards, A&E, UK | Pre/Post | 68 computer terminals (keyboards/ mice) | Samples taken on different sides of keyboard and mouse using dip slides coated with nutrient and Baird parker agars. After sampling, keyboard/mouse exposed to UV device and resampled. | Total bacterial load | Astroplast Nano-UV disinfectant light scanner |
| **SYKES 2006** | Unknown clinical setting, UK | Repeated cross sectional over 3 months | 5 ultrasound machine keyboards | 5 machines sampled randomly on different days of the week and at different times over a period of 3 months (total of 15 times). Sampled using moistened swab by person wearing sterile gloves. | Total bacterial load | |
| **TAN 2013** | 2 open wards in a 800 bed acute care hospital, Singapore | Cross sectional | Unknown number of keyboards | Sampling carried out over a 2-month period. Neither cleaning nor ward staff were informed about the sampling, which was performed at random intervals (equally during morning and afternoon periods) during the routine working day by non-ward-based technologists. Keyboards were sampled by moving a sterile flocked nylon moistened swab over the letter keys. | Presence of MRSA, E. coli and K. pneumoniae resistant to third-generation cephalosporins, CRAB and VRE. | |
| **TROCHESSET 2012** | School of Dental Medicine US | Repeated cross sectional, 8 times over 62 weeks | Unknown number of keyboards and mice | Sampling conducted 8 times over a 62-week period (not clear if all surfaces were sampled all 8 times). Sampling dates were at least one month apart. Done between 1 p.m. and 2 p.m., when patient care was not being delivered, in-between patients. One researcher immersed | Detection of S. aureus | |

| AUTHOR, YEAR | SETTING | STUDY DESIGN | SAMPLE SIZE* | MICROBIOLOGICAL SAMPLING | OUTCOME MEASURE(S) | INTERVENTION DESCRIPTION (IF ANY) |
|---|---|---|---|---|---|---|
| | | | | sterile polyester fiber–tipped swabs in sterile saline for 1 second and sampled the surfaces by rubbing the moistened swab over the object for 10 seconds. | | |
| **WAGHORN 2005** | Various clinical wards, ICU, A&E, OPD, OR, UK | Cross Sectional | 48 keyboards | Moistened sterile swabs rubbed over each keyboard surface including any mice | Total bacterial load and degree of growth (including S. aureus, hemolytic streptococci, P. aeruginosa and C. diff) | |
| **WESTERWAY 2017** | Ultrasound units in a public hospital and private practice, Australia | Cross Sectional | 10 ultrasound keyboards | Keyboards sampled using sterilin transport swabs | Total bacterial load | |
| **WILSON 2006** | ICU, UK | Cross Sectional | 17 keyboards | 51 samples collected using contact plates. Keyboards sampled daily until patients left the bed space. | Total bacterial load | |
| **WILSON 2008** | ICU, UK | Controlled Trial | 32 keyboards | Sampling conducted on 10 days over a 2-week period (80 samples total) between 11am-12pm each day using contact plates. | Detection of S. aureus and Acinetobacter sp. | Comparison of 3 types of keyboards: Medigenic (gives alarm when cleaning is required), Anonymous brand, and standard keyboards |
| **WILSON 2011** | ICU at 2 teaching hospitals, UK | Prospective randomized cross-over | Unknown number of keyboards | Direct contact method was used using dip slides; performed 3 times daily (before cleaning, middle of day, after cleaning) on 3 days per week for 48 weeks | Total aerobic colony count | Enhanced cleaning: extra twice daily cleaning using cloths soaked in a copper-based biocidal formulation |
| **XU 2017** | Medical ICU and NICU, China | Pre/Post | Unknown number of keyboards and mice | Sampling was performed by infection control professionals at 10 AM every quarter. Mouse, 10 letter keys and 10 number keys were sampled using neutralizer moistened sterile swabs. | Detection of MRSA | Traditional cotton cloth and bucket system vs. disinfectant wipes |
| **YUN 2012** | Patient rooms in burn ICU | Cross sectional | Unknown number of | Two swabs (one for TCM and one for PCR/ESI-TOF-MS) were obtained using a standard rolling | Total bacterial load | |

| AUTHOR, YEAR | SETTING | STUDY DESIGN | SAMPLE SIZE* | MICROBIOLOGICAL SAMPLING | OUTCOME MEASURE(S) | INTERVENTION DESCRIPTION (IF ANY) |
|---|---|---|---|---|---|---|
| | and orthopedic ward USA | | keyboards and mice | technique from the keyboard and mouse in each of the 20 patient rooms, where available | | |

*Some studies with sample size "unknown number of keyboards" reported only number of samples taken, not total devices used.

Abbreviations: A. baumannii = Acinetobacter baumannii, ACC = Aerobic Colony Counts, A&E = Accident and Emergency Unit, ATM = Amies transport medium, ATP = Adenosine triphosphate, C. Diff = Clostridium difficile, CFU = Colony forming units, CNS = Coagulase-negative staphylococcus, CRAB = Carbapenem-resistant Acinetobacter baumannii, E. Coli = Escherichia coli, ER = Emergency room, GI = gastrointestinal, ICU = Intensive care unit, K. pneumonia = Klebsiella pneumonia, MRSA = Methicillin-resistant Staphylococcus aureus, MSSA = Methicillin-sensitive Staphylococcus aureus, NICU = Neonatal Intensive Care Unit, NoV = Norovirus, OR = Operating room, OPD = Outpatient Department, P. aeruginosa = Pseudomonas aeruginosa, RCT = Randomized Controlled Trial, RLU = Relative light units, S. aureus = Staphylococcus aureus, TCM = Traditional clinical microbiology, VRE = Vancomycin-resistant Enterococcus

## Supplementary File 4: Studies reporting overall contamination as colony forming units (CFU)

| AUTHOR, YEAR | SETTING | DEVICE AND NUMBER | CONTAMINATION MEASURED USING CFUs |
|---|---|---|---|
| **ALBRECHT 2013** | 10 clinical wards | 10 iPads | 1842 total CFU found overall iPads (162 median CFU per device) |
| **AL-HAMAD 2008** | Nurse station in hospital | Unknown number of keyboards | From nurse station areas without cleaning policy: 4 CFU/cm² (± SE: 2.75, 5.25) |
| **CHOI 2014** | Endoscopy rooms of 2 tertiary hospitals | Unknown number of keyboards and mice | Doctor's computer keyboard: 974 CFU<br>Nurse's computer mouse: 764 CFU<br>Doctor's computer mouse: 180 CFU<br>Endoscopy keyboard: 595 CFU (approx. from graph) |
| **FARIAS 2017** | Renal transplant ward in tertiary hospital | 1 keyboard | <20 CFU/100 cm² |
| **FUKADA 2008** | OR, ICU, consulting room and outpatient reception area | Unknown number of keyboards | Mean bacterial counts CFU/ml (SD):<br>OR: 333 (141)<br>ICU: 1015 (501)<br>Consulting room and reception area for outpatients: 1113 (1420) |
| **GERBA 2016** | Hospital | 17 computer touch screens | Average number of bacteria on touch screens was 2,257 CFUs (800-1,000/ cm²). |
| **JONES 2015** | ICU | 8 keyboards for controlled study + 24 keyboards for intervention | 57% keyboards had contamination of >500 CFU before cleaning |
| **JUNGNICKEL 2014** | Several clinical departments and wards at a Medical School | 5 iPads | 2,033 CFU in total (median: 416) counted on the 5 devices |
| **LINK 2016** | Operating room | Unknown number of keyboards and mice | Median CFU/cm² (min, max):<br>Keyboard: 0.47 (9.9, 61.67)<br>Mouse: 0.26 (0.0, 35.26) |
| **MALTA 2016** | Dental radiology clinic at a public educational institution | Unknown number of keyboard and mice on radiological equipment | Intraoral: (mean CFU before/after clinical use)<br>Cocci: mouse (.05/0) keyboard (0.1/0.01)<br>GNB: mouse (0/0), keyboard (0/0)<br>Fungi: mouse (5.9/0.05), keyboard (0.78/0.13)<br>Extraoral:<br>Cocci: mouse (0.03/0.1) keyboard (0.46/0.2)<br>GNB: mouse (0.01/0) keyboard (0.2/0.36)<br>Fungi: mouse (0.18/0.01) keyboard (0.36/0.16) |
| **MOTTA 2007** | Undergrad dental school clinic | 4 keyboards | Mean CFU ranged from 0.23 to 1.03 before, 2.26 to 2.64 during, and 0.66 to 1.46 after clinical procedures. |
| **WILSON 2008** | ICU | 32 keyboards | For Medigenic keyboards, baseline contamination rates ranged from 38-65 CFU, depending on the alarm interval set |

Abbreviations: CFU = Colony forming units, ICU = Intensive care unit, OR = Operating room, SD = Standard deviation

## Supplementary File 5: Studies reporting overall contamination using other quantitative methods

| AUTHOR YEAR | SETTING | DEVICE AND NUMBER | OUTCOME MEASURES | CONTAMINATION MEASURED USING OTHER QUANTITATIVE METHODS |
|---|---|---|---|---|
| **CATANO 2012** | Tertiary hospital | 30 keyboards | Total bacterial load | 39 isolations obtained from the 30 keyboards; 56.4% of isolations considered potentially clinically relevant |
| **DANCER 2008** | 2 acute surgical wards at a teaching hospital | 2 keyboards (52 total swabs) | Hygiene failure (a site with ACC > 2.5 CFU/cm2 or any site with the presence of MSSA or MRSA | 13/52 swabs |
| **HARDY 2014** | All wards in 3 hospitals | Unknown number of computer keyboards and COWs | Percentage of times each of the sites failed (>1,000 RLU) ATP monitoring | Computers on wheels: 33.1%<br>Keyboards: 34.7% |
| **HARTMANN 2004** | ICU | Unknown number of keyboards and mice | Potentially pathogenic microorganisms (2+ CFU) | Keyboards: 15/238 (6.3%) of samples<br>Mice: 13/238 (5.5%) of samples |
| **MAN 2002** | Nurse stations, patient bed bays in a number of different wards | 85 computer keyboards + 80 mice + 44 mouse pads | Total bacterial load | 40/85 (47%) keyboards, 36/80 (45%) mice, and 15/44 (34%) mouse pads yielded multiple bacterial species |
| **MOORE 2013** | ICU and GI surgical wards | Unclear # of keyboards | Aerobic colony counts | GI ward: 8/66 (12%) keyboards contaminated at levels > 100 CFU/ 25 $cm^2$ on at least 1 occasion<br>Data for ICU not reported |
| **PUGLIESE 2011** | Emergency dept | 72 keyboards | Total bacterial load | 10 (13.8%) colonized with 9 different identified bacteria |
| **RASTOGI 2012** | NICU | 3 keyboards | Total bacterial load | 5 positive cultures obtained from keyboards |
| **SAITO 2015** | Six ORs | 12 keyboards and 6 touch screens | mean ATP value (log10 RLU) | Keyboards for nurses: 2.8 +/- 0.3<br>Keyboards for anesthesiologists: 2.8 +/- 0.3<br>Touch screens for anesthesiologists: 2.0 +/- 0.3 |
| **SYKES 2006** | Unknown clinical setting, UK | 5 ultrasound machine keyboards | Total bacterial load | Pathogens identified: Acinetobacter (2 keyboards), Acinetobacter lwoffii, Enterococcus faecium, Enterococcus faecalis, Pseudomonas putida, S. aureus (fully sensitive) |

Abbreviations: ACC = Aerobic Colony Counts, ATP = Adenosine triphosphate, CFU = Colony forming units, COWs = computers on wheels, GI = gastrointestinal, ICU = Intensive care unit, NICU = Neonatal Intensive Care Unit, OR = Operating room, RLU = Relative light units, S. aureus = Staphylococcus aureus

## Supplementary File 6: Studies reporting overall contamination only of a single or specific pathogens

| AUTHOR YEAR | SETTING | DEVICE AND NUMBER | OUTCOME MEASURES | CONTAMINATION MEASURED |
|---|---|---|---|---|
| **ALI 2015** | Teaching hospital | Unknown number of keyboards | Detection of C. diff | C. diff detected using sponge swab: 3/15 (20%) |
| **ANASTAS-IADES 2009** | ICUs at Academic Hospital | 14 keyboards and 14 mice | Detection of CNS, Gram-positive bacilli, micrococci, fungi and S. aureus | First round of screening: (Keyboards\|Mice):<br>S. aureus: 0/14 (0%) \| 1/14 (7.1%)<br>CNS: 14/14 (100%) \| 14/14 (100%)<br>Others (estimated colony counts):<br>Gram positive bacilli: 193 \| 28<br>Micrococcus: 2 \| 3<br>Fungi: 14 \| 0 |
| **CIRAGIL 2006** | Patient and exam rooms, OR, offices, non-clinical areas | 56 keyboards in clinical areas | Total bacterial load | MSSE: 23/56 (41.1%)<br>Bacillus: 21/56 (37.5%)<br>Enterococcus: 7/56 (12.5%)<br>MSSA: 1/56 (1.8%)<br>Enterobacter: 6/56 (10.7%)<br>Sphingomonas paucimobilis: 1 (2%)<br>Streptococcus: 1/56 (1.8%)<br>E. coli: 4/56 (7.1%)<br>Corynebacterium: 1/56 (1.8%)<br>Klebsiella ozanae: 1/56 (1.8%) |
| **DEVINE 2001** | Nurse stations in 2 district hospital acute medical and surgical wards | 25 terminals (keyboard, mouse, mouse pad) | Detection of MRSA | MRSA: 24% total<br>(42% in hospital A and 8% in hospital B) |
| **DUMFORD 2009** | Patient rooms, physician and nurse work areas, portable equipment, 3 wards | 32 computers in initial survey, 25 computers and 1 mouse in follow up survey | Detection of C. diff | C. diff: 9/32 (28%) |
| **ENGELHART 2008** | Non-clinical and clinical areas of a University Hospital | 77 computer terminals in clinical areas (keyboard, mouse) | Total bacterial load | S. aureus: 10/77 (13%)<br>Viridans streptococci (Gram-pos bacteria): 8/77 (10.4%)<br>Enterococci: 7/77 (9.1%)<br>Gram negative: 13/77 (16.9%)<br>Molds: 17/77 (22.1%) |
| **FAIRES 2012** | 3 community hospitals | Unknown number of keyboards | Detection of MRSA or C. Diff | At each hospital:<br>MRSA: 0/8 (0%) samples, 2/29 (6.9%) samples, 2/25 (8.0%) samples<br>C. diff: 0/9 (0%), 0/29 (0%), 3/25 (12%) |
| **FAIRES 2013** | 2 Medical wards and 1 surgical ward | Unknown number of keyboards | Detection of MRSA or C. Diff | MRSA: 1/55 samples (1.8%)<br>C. diff: 3/55 (5.5%) |

| | | | | |
|---|---|---|---|---|
| **FELLOWES 2006** | General clinical hospital areas | 44 keyboards | Detection of MRSA or MSSA | MSSA: 9/44 (20%)<br>MRSA: 4/44 (9%) |
| **GRABSCH 2012** | Hospital | Unknown number of keyboards | Detection of VRE | VRE: 1/9 (11%) swabs |
| **HIRSCH 2014** | University department of pharmacy practice | 30 iPads | Total bacterial load | S. aureus: 22/30 (73.3%)<br>MRSA: 15/30 (50%)<br>Enterococci: 30/30 (100%)<br>VRE: 1/30 (3.3%)<br>CNS: 29/30 (96.7%) |
| **KIEDROWSKI 2013** | Hospital | 20 iPads | Detection of C. diff, MRSA | S. aureus: 3/20 (15%)<br>C. diff: 0/30 (0%)<br>Gram-negative: 0/30 (0%) |
| **LU 2009** | All ward stations of university hospital | 282 stations (keyboard and mouse) | Detection of S. aureus, Pseudomonas, Acinetobacter | MRSA: 3/282 (1.1%)<br>MSSA: 15/282 (5.3%)<br>A. baumannii: 12/282 (4.3%)<br>Other Acinetobacter: 10/282 (3.5%)<br>Pseudomonas: 17/282 (6%) (but none were P. aeruginosa) |
| **MESSINA 2013 (A)** | 4 different medical units | 27 keyboards | Total bacteria count of: Staphylococcus, Pseudomonas, E. coli, total coliform bacteria, C. diff, Acinetobacter | Acinetobacter: 1 (3.7%)<br>E. coli: 11 (40.7%)<br>Coliforms: 21 (77.8%)<br>Enterococci: 4 (14.8%)<br>Staphylococci: 25 (92.6%)<br>MRSA: 6 (22.2%)<br>Molds: 20 (74.1%) |
| **OGUZKAYA-ARTAN 2015** | ED | 14 keyboards + 5 desktop surfaces | Detection of S. aureus | MRSA: 1/14 (7%) |
| **OIE 2005** | Dermatology ward | 1 keyboard | Detection of S. aureus | MRSA: 0/4 (0%) |
| **OTTER 2011** | Hospital ED and an outpatient HIV clinic | Unknown number of keyboards | Detection of MRSA | MRSA identified on 3 keyboards in the ED and 0 keyboards in the HIV outpatient clinic. |
| **PHUMISANTIPHONG 2009** | Hospital patient rooms and nurse station | 30 computer terminals (keyboards/mice) | Detection of CRAB | A. baumannii: 3.3% (none were CRAB) |
| **REEM 2014** | Exam and imaging rooms, common areas in ophthalmology clinic | 16 keyboards | Detection of MRSA/MSSA | S. aureus: 7/24 (29.2%)<br>MRSA: 1/24 (4.2%)<br>MSSA: 5/24 (20.8%) |
| **SENOK 2015** | ICU nursing stations | Unknown number of keyboards and mice | Detection of A. baumannii isolates | One MRAB isolate identified on a computer mouse |
| **STAMBAUGH 2009** | Dental office | 88 keyboards or mice | Detection of Multidrug-resistant organisms | S. aureus: 8/88 (9%)<br>Lactose-fermenting gram-negative rods: 22/88 (25%)<br>CNS: 78/88 (88.6%) |

| | | | | |
|---|---|---|---|---|
| | | | | Bacillus: 23%<br>Enterococcus: 2%<br>Gram-negative rods: 2% |
| **TROCHESSET 2012** | School of Dental Medicine | Unknown number of keyboards and mice | Detection of S. aureus | S. aureus:<br>Keyboards: 4/47 (8.5%)<br>Mice: 0/4 (0%) |
| **XU 2017** | Medical ICU and neonatal ICU | Unknown number of keyboards and mice | Detection of MRSA | MRSA: 7/19 (36.8%) |

Abbreviations: A. baumannii = Acinetobacter baumannii, C. Diff = Clostridium difficile, CNS = Coagulase-negative staphylococcus, CRAB = Carbapenem-resistant Acinetobacter baumannii, E. Coli = Escherichia coli, ED = Emergency department, ICU = Intensive care unit, MRSA = Methicillin-resistant Staphylococcus aureus, MSSA = Methicillin-sensitive Staphylococcus aureus, MSSE = Methicillin-susceptible Staphylococcus epidermidis, OR = Operating room, P. aeruginosa = Pseudomonas aeruginosa, S. aureus = Staphylococcus aureus, VRE = Vancomycin-resistant Enterococcus

## Supplementary File 7: Studies reporting proportion of devices contaminated at baseline with specific types of microbes (including pathogens)

| AUTHOR, YEAR | DEVICE AND NUMBER | OUTCOME MEASURES | OVERALL BASELINE CONTAMINATION PREVALENCE | ALL S. AUREUS | MRSA | MSSA | ENTERO-COCCI: NON-VRE, OR NOT SPECIFIED | VRE | SKIN BACTERIA * | OTHER GRAM POSITIVES ** | GRAM NEG. RODS/ BACILLI *** | ENTERO-BACTER | C. DIFF | COLIFORMS NON-LACTOSE FERMENTERS **** | OTHERS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **ALBRECHT 2013** | 10 iPads | Total bacterial load | 1842 total CFU found on iPads in the clinical setting (162 median CFU) | | | | | | Micrococci: 25.7% | | | | | | All staphy-lococci: 59.9% |
| **ALI 2015** | Unknown number of keyboards | Detection of C. diff | C.diff detected using Brazier's contact plate: 0/5 (0%) Using Sponge swab: 3/15 (20%) | | | | | | | | | | 3/15 (20%) | | |
| **ANASTASIADES 2009** | 14 keyboards (K) and 14 mice (M) | Detection of CNS, Gram-positive bacilli, micrococci, fungi and S. aureus | | Round 1 K: 0/14 (0%) Round 1 M: 1/14 (7.1%) | | | | | Round 1 K: 14/14 (100%) Round 1 M: 14/14 (100%) | | | | | | |
| **BURES 2000** | 10 keyboards *specific pathogen rates include 8 faucet handles (144 samples) | Total bacterial load | 19/80 keyboard samples taken (24%) | | 16/144 (11.1%) | | 6/144 (4.2%) | | | | 7/144 (4.9%) | 4/144 (2.8%) | | | |
| **CATANO 2012** | 30 keyboards | Total bacterial load | 39 isolations from 30 keyboards; 56.4% | | | | 3/39 (7.7%) | | Bacillus: 17/39 (43.5%) MRSE: | | 3/39 (7.7%) | | | | Either MSSE, MSSA, MSSW, |

| AUTHOR, YEAR | DEVICE AND NUMBER | OUTCOME MEASURES | OVERALL BASELINE CONTAMINATION PREVALENCE | ALL S. AUREUS | MRSA | MSSA | ENTERO-COCCI: NON-VRE, OR NOT SPECIFIED | VRE | SKIN BACTERIA * | OTHER GRAM POSITIVES ** | GRAM NEG. RODS/ BACILLI *** | ENTERO-BACTER | C. DIFF | COLIFORMS NON-LACTOSE FERMENTERS **** | OTHERS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | were potentially clinically relevant | | | | | | 2/39 (5.1%) | | | | | | MSSH: 14/39 (35.9%) |
| **CIRAGIL 2006** | 56 keyboards in clinical areas | Total bacterial load | | | | 1/56 (1.8%) | 7/56 (12.5%) | | MSSE 23/56 (41.1%), Bacillus spp. 21/56 (37.5%), Corynebacterium 1/56 (1.8%) | Streptococus sp 1/56 (1.8%) | E. Coli 4/56 (7.1%), Klebsiella ozanae 1/56 (1.8%) Sphingomonas 1/56 (1.8%) | | | | |
| **CORDEIRO 2015** | 6 keyboards | Total bacterial load | 6/6 (100%) | | | | | | Non-spec CNS: 5/6 (83.3: 5/6 (83.3%) S. epi: 1/6 (16.7%) | | | | | | |
| **DANCER 2008** | 2 keyboards (52 total samples) | ACC greater than 2.5 CFU/cm$^2$ or any site with presence of MSSA or MRSA | 13/52 | | 1/52 | 2/52 | | | | | | | | | |

| AUTHOR, YEAR | DEVICE AND NUMBER | OUTCOME MEASURES | OVERALL BASELINE CONTAMINATION PREVALENCE | ALL S. AUREUS | MRSA | MSSA | ENTERO-COCCI: NON-VRE, OR NOT SPECIFIED | VRE | SKIN BACTERIA * | OTHER GRAM POSITIVES ** | GRAM NEG. RODS/ BACILLI *** | ENTERO-BACTER | C. DIFF | COLIFORMS NON-LACTOSE FERMENTERS **** | OTHERS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **DE GROOD 2012** | 230 keyboards | Total bacterial load | 99.6% (229/230) positive for one of CNS, Micrococcus, diptheroids, Bacillus spp. or alpha strep. And: 67% positive with any one of: MSSA, MRSA, Enterococcus (non VRE and VRE), GNB, C. diff, Yeast, fungus | | 17/230 (7.4%) | 21/230 (9.1%) | 58/230 (25.2%) | 9/130 (3.9%) | 229/230 (99.6%) | | 68/230 (29.6%) | | 0 (0%) | 21/230 (9.1%) | Yeast/ fungus: 5/230 (2.2%) |
| **DEVINE 2001** | 25 terminals (keyboard + mouse + pad) | Detection of MRSA | MRSA: 24% (42% in hospital A and 8% in hospital B) | | 6/25 (24%) | | | | | | | | | | |
| **DUMFORD 2009** | 32 compu-ters | C. diff | 9/32 (28%) contaminated with C. diff | | | | | | | | | | 9/32 (28%) | | |
| **DUSZAK 2014** | 7 mice | Total bacterial load | 100% had bacterial growth (mean colony counts: 46.1 ± 58.1) | 5/7 (71.4%) | | | | | CNS: 2/7 (28.6%) | | 2/7 (28.6%) | | | | |
| **ENGELHART 2008** | 77 computer terminals in clinical areas | Total bacterial load | Not reported for keyboards separately | 10/77 (13%) | | | 7/77 (9.1%) | | | Viridans streptococci: 8/77 (10.4%) | 13/77 (16.9%) | | | | Molds: 17/77 (22.1%) |

| AUTHOR, YEAR | DEVICE AND NUMBER | OUTCOME MEASURES | OVERALL BASELINE CONTAMINATION PREVALENCE | ALL S. AUREUS | MRSA | MSSA | ENTERO-COCCI: NON-VRE, OR NOT SPECIFIED | VRE | SKIN BACTERIA * | OTHER GRAM POSITIVES ** | GRAM NEG. RODS/ BACILLI *** | ENTERO-BACTER | C. DIFF | COLIFORMS NON-LACTOSE FERMENTERS **** | OTHERS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **FAIRES 2012** | Unknown number of keyboards | Detection of MRSA or C Diff | Medical wards: MRSA: between 8.2% and 14.8% C.Diff: 0 to 3.9% Surgical wards: MRSA: 12.5% to 13.2% C.Diff: 1.5% to 6.2% | | 4 (6.4%) | | | | | | | | 3 (4.8%) | | |
| **FAIRES 2013** | Unknown number of keyboards | Detection of MRSA or C. Diff (55 samples) | | | 1/55 (1.8%) | | | | | | | | 3/55 (5.5%) | | |
| **FELLOWES 2006** | 44 keyboards | Detection of MRSA or MSSA | MSSA: 9/44 (20%) MRSA: 4/44 (9%) | | 4/44 (9%) | 9/44 (20%) | | | | | | | | | |
| **GERBA 2016** | 17 computer touch screens | Coliform bacterial growth | Average number of bacteria: 2,257 CFU | | | | | 2/17 (12%) | S. epi: 6/17 (35%), Micrococc. luteus: 3/17 (18%), Micrococcus sp: 1/17 (6%), kytococcus sedentarius 2/17 (12%), S. caprae: 1/17 (6%), Kocuria varians: 1/17 (6%) | | Klebsiella: 2/17 (12%) | | 2/17 (12%) | | |

| AUTHOR, YEAR | DEVICE AND NUMBER | OUTCOME MEASURES | OVERALL BASELINE CONTAMINATION PREVALENCE | ALL S. AUREUS | MRSA | MSSA | ENTERO-COCCI: NON-VRE, OR NOT SPECIFIED | VRE | SKIN BACTERIA * | OTHER GRAM POSITIVES ** | GRAM NEG. RODS/ BACILLI *** | ENTERO-BACTER | C. DIFF | COLIFORMS NON-LACTOSE FERMENTERS **** | OTHERS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **GOSTINE 2016** | 40 keyboards (230 total samples) | Total bacterial load | 193/203 (95.1%) of samples positive for bacteria, median of 120 CFUs per keyboard | 12/203 (5.9%) | 3/203 (1.5%) | | 8/203 (3.9%) | 2/203 (1%) | | | Klebsiella 3/203 (1.5%) | 6/203 (3%) | | Pseudomonas: 1/203 (0.5%), Acinetobacter: 1/203 (0.5%) | |
| **GRABSCH 2012** | Unknown number of keyboards | Detection of VRE | 1/9 (11%) swabs were VRE positive | | | | | 1/9 (11%) | | | | | | | |
| **GRAY 2007** | 7 mice (63 samples) | Total bacterial load | 54/63 (85.7%) samples positive | 2/63 (3%) | | | | | CNS: 52/63 (83%), Micrococcus: 36/63 (57%), Bacillus: 26/63 (41%) | | | | | | Coccobacillus: 7/63 (9%) |
| **HARTMANN 2004** | Unknown number of keyboards (K) and mice (M)<br><br>238 samples taken of each | Potentially pathogenic microorganisms (2+ CFU) | (In patient rooms + central ward):<br><br><u>Keyboards</u>: 15/238 (6.3%)<br><u>Mice</u>: 13/238 (5.5%) | K: 3/238 (1.3%)<br><br>M: 15/238 (6.3%) | | | K: 12/238 (5%)<br><br>M: 2/238 (0.9%) | | K: Micrococcus: 134/238 (56.3%), S. Epi: 205/238 (86.1%) Other Staph sp: 78/238 (32.8%)<br><br>M: Micrococcus: 65/238 (27.3%), | | K: 2/238 (0.8%)<br><br>M: 0/238 | | | | Mold: K: 5/238 (2.1%)<br><br>M: 2/238 (0.8%) |

| AUTHOR, YEAR | DEVICE AND NUMBER | OUTCOME MEASURES | OVERALL BASELINE CONTAMINATION PREVALENCE | ALL S. AUREUS | MRSA | MSSA | ENTERO-COCCI: NON-VRE, OR NOT SPECIFIED | VRE | SKIN BACTERIA * | OTHER GRAM POSITIVES ** | GRAM NEG. RODS/ BACILLI *** | ENTERO-BACTER | C. DIFF | COLIFORMS NON-LACTOSE FERMENTERS **** | OTHERS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | S. Epi: 182/238 (76.5%), Other Staph Sp: 60/238 (25.2%) | | | | | | |
| **HASSAN 2014** | 150 keyboards and 100 mice | Total bacterial load | 242/250 (99.2%) | 198 (79.2%) | | | 93 (37.2%) | | S. Epi 172 (68.8%) | Strepto coccus 28 (11.2%) | GNB 201 (80.4%) E. Coli 45 (18%) | | | | |
| **HIRSCH 2014** | 30 iPads | Total bacterial load | | 22/30 (73.3%) | 15/30 (50%) | | 30/30 (100%) | 1/30 (3.3%) | CNS: 29/30 (96.7%) | | | | | | |
| **HONG 2012** | 112 items (56 keyboards and 56 mice) | Total bacterial load | 103/112 (92.0%) Keyboards: 98.2% Mice: 85.7% | | K: MRSA: 2/56 (1.8%) | K: MSSA: 2/56 (1.8%) | | | K: CNS: 51/56 (91.1%) Bacillus: 14/56 (25%) Micro-co-ccus: 13/56 (23.2%) M: CNS: 45/56 (80.4%) Bacillus: 5/56 (8.9%) Micrococcus: 6/56 (10.7%) | | M: GNR: 1/56 (0.9%) | | | | K: Molds: 3/56 (2.7%) |

| AUTHOR, YEAR | DEVICE AND NUMBER | OUTCOME MEASURES | OVERALL BASELINE CONTAMINATION PREVALENCE | ALL S. AUREUS | MRSA | MSSA | ENTERO-COCCI: NON-VRE, OR NOT SPECIFIED | VRE | SKIN BACTERIA * | OTHER GRAM POSITIVES ** | GRAM NEG. RODS/ BACILLI *** | ENTERO-BACTER | C. DIFF | COLIFORMS NON-LACTOSE FERMENTERS **** | OTHERS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **KARBASIZ-ADE 2014** | 65 Keyboards | Total bacterial load | 64/65 (98.5%) | 15/65 (23.1%) | 10/65 (15%) | | | | Bacillus: 45/65 (69.2%), CNS: 16/65 (24.6%), Micrococcus: 5/65 (7.7%) | Actinomycet sp: 1/65 (1.5%) | E. coli: 1/65 (1.5%) | 1/65 (1.5%) | | Citrobacter: 2/65 (3.1%), A. baumannii: 3/65 (4.6%) | |
| **KEERASUN TONPONG 2017** | 26 keyboards | Total bacterial load | 25/26 (96.2%) | | | | | | CNS: 25/26 (96.2%) Bacillus spp: 8/26 (30.8%) | Gram pos bacilli: 1/26 (3.8%) | NF-GNB: 3/26 (11.5%) | | | | Fungi: 8/26 (30.8%) |
| **KHAN 2015** | 106 portable electronic devices (93 were tablets) | Total bacterial load | 100% had at least 1 positive culture from screen or cover | 11/106 (10.4%) | | | 3/106 (2.8%) | | | | 7/106 (6.6%) | 1/106 (0.9%) | | 3/106 (2.8%) | |
| **KIEDROWSKI 2013** | 20 iPads | Detection of C.diff, MRSA | 3/20 (15%) iPads grew S aureus. No growth of C. diff. nor any gram-negative pathogens | 3/20 (15%) | | | | | | | 0 | | 0 | | |
| **LU 2009** | 282 stations (keyboard + mouse) | S. aureus, Pseudomonas sp, Acinetobacter sp. | 49/282 (17.4%) positive for S. aureus, Acinetobacter spp. or Pseudomonas spp | | 3/282 (1.1%) | 15/282 (5.3%) | | | | | | | | 29/282 (10.3%) | |

| AUTHOR, YEAR | DEVICE AND NUMBER | OUTCOME MEASURES | OVERALL BASELINE CONTAMINATION PREVALENCE | ALL S. AUREUS | MRSA | MSSA | ENTERO-COCCI: NON-VRE, OR NOT SPECIFIED | VRE | SKIN BACTERIA * | OTHER GRAM POSITIVES ** | GRAM NEG. RODS/ BACILLI *** | ENTERO-BACTER | C. DIFF | COLIFORMS NON-LACTOSE FERMENTERS **** | OTHERS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **MAN 2002** | 85 keyboards + 80 mice + 44 pads | Total bacterial load | 40 keyboards (47%), 36 mice (45%), and 15 mouse pads (34%) yielded multiple bacterial species. | 27/209 (12.9%) | 2/209 (1%) | | 14/209 (6.7%) | | Bacillus: 123/209 (58.9%) Staph epi: 103/209 (49.3%) | Strep spp: 16/209 (7.7%) | 26/209 (12.4%) | | | Pseudo-monas spp: 3/209 (1.4%) | |
| **MESSINA 2013 (A)** | 27 computer keyboards | Total bacteria count of: Staphyloccus spp, Pseudomonas spp, E. coli, total coliform bacteria, Acinetobacter spp, C.diff | | 25/27 (92.6%) | 6/27 (22.2%) | | 4/27 (14.8%) | | | | E .coli: 11/27 (40.7%) | | | Coliform 21/27 (77.8%) | Molds: 20/27 (74.1%) |
| **MESSINA 2013 (B)** | 50 keyboards | Total bacterial load | With PCA 36°C: 49/50 (98%) With PCA 22°C: 33/50 (66%) | 47/50 (94%) | 8/50 (16%) | | 5/50 (10%) | | | | E coli: 17/50 (34%) | | | Coliform 39/50 (78%) | Molds: 26/50 (52%) |
| **OGUZKAYA-ARTAN 2015** | 14 keyboards + 5 desktop surfaces | S. aureus isolates | 1/14 (7%) were MRSA positive | | 1/14 (7%) | | | | | | | | | | |
| **OIE 2005** | 1 keyboard | S. aureus isolates | MSSA: 3.3 +/- 7.5 (mean, S.D.) on 4 samples | | 0/4 (0%) | | | | | | | | | | |

| AUTHOR, YEAR | DEVICE AND NUMBER | OUTCOME MEASURES | OVERALL BASELINE CONTAMINATION PREVALENCE | ALL S. AUREUS | MRSA | MSSA | ENTERO-COCCI: NON-VRE, OR NOT SPECIFIED | VRE | SKIN BACTERIA * | OTHER GRAM POSITIVES ** | GRAM NEG. RODS/ BACILLI *** | ENTERO-BACTER | C. DIFF | COLIFORMS NON-LACTOSE FERMENTERS **** | OTHERS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **PHUMISANTIPHONG 2009** | 30 computer terminals (keyboard + mice) | Detection of CRAB | keyboards/mice at nurse station had lowest contamination rate of A. baumannii (3.3%) of all the sampled locations. No CRAB identified. | | | | | | | | | | | 3.3% | |
| **PUGLIESE 2011** | 72 keyboards | Total bacterial load | 10/72 (13.8%) colonized with 9 different bacteria | | 1/72 (1.4%) | 1/72 (1.4%) | | 1/72 (1.4%) | | | 9/72 (12.5%) includes E. coli, Pseudomonas, Sphing, Pantoea, and 2 without ID | | 0/72 | | |
| **REEM 2014** | 16 keyboards (24 total samples) | MRSA /MSSA isolates | 7/24 (29.2%) samples positive for MSSA, MRSA, or MRSP | 7/24 (29.2%) | 1/24 (4.2%) | 5/24 (20.8%) | | | | | | | | | |
| **RUTALA 2006** | 25 keyboards | Total bacterial load | 100% had at least one potential pathogen | 2/25 (8%) | ORSA 1/25 (4%) | OSSA 1/25 (4%) | 3/25 (12%) | 0 | CNS 25/25 (100%) Diphtheroids 20/25 (80%) Micrococcus 18/25 (72%) Bacillus 16/25 (64%) Propioniba | Alpha streptococci 6/25 (21%) Viridans streptococci 2/25 (8%) | | | | NF-GNR 9/25 (36%) | Fungi 6/25 (24%) |

| AUTHOR, YEAR | DEVICE AND NUMBER | OUTCOME MEASURES | OVERALL BASELINE CONTAMINATION PREVALENCE | ALL S. AUREUS | MRSA | MSSA | ENTERO-COCCI: NON-VRE, OR NOT SPECIFIED | VRE | SKIN BACTERIA * | OTHER GRAM POSITIVES ** | GRAM NEG. RODS/ BACILLI *** | ENTERO-BACTER | C. DIFF | COLIFORMS NON-LACTOSE FERMENTERS **** | OTHERS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | cteria 7/25 (28%) | | | | | | |
| **SCHULTZ 2003** | 100 keyboards | Total bacterial load | 95/100 (95%) had growth of 1+ microorganisms | 1/100 (1%) | | | 3/100 (3%) | 1/100 (1%) | CNS: 84/100 (84%) Bacillus sp: 44/100 (44%) Corynebact 8/100 (8%) | Strepto cocci: 9/100 (9%) | 6/100 (6%) | | | 2/100 (2%) | Clostridium perfringens: 4/100 (4%) |
| **SHAIKH 2016** | 25 keyboards | Total bacterial load | 20/25 (80%) contaminated with any potential pathogen | 2/25 (8%) | | | 15/25 (60%) | | | | 1/25 (4%) | | 2/25 (8%) | | |
| **SMITH 2006** | 60 notebook keys and grips | Total bacterial load | 52/120 (43%) cultures positive, but significant pathogens were found in only 2/120 (1.7%) of cultures | | | 1/120 (0.8%) | | | CNS 39/120, Diphtheroids-coryne bacterium 5/120, Micrococcus 13/120 | Alpha-hemolytic strep 4/120 | Serratia 1/120 (0.8%) | | | | |
| **STAMBAUGH 2009** | 88 keyboards or mice | Detection of Multidrug-resistant organisms | | 8/88 (9%) | | | 2/88 (2%) | | Bacillus: 20/88 (23%) CNS: 78/88 (88.6%) | | Lactose fermenting GNR: 22/88 (25%) Other GNR: 2/88 (2%) | | | | |

| AUTHOR, YEAR | DEVICE AND NUMBER | OUTCOME MEASURES | OVERALL BASELINE CONTAMINATION PREVALENCE | ALL S. AUREUS | MRSA | MSSA | ENTERO-COCCI: NON-VRE, OR NOT SPECIFIED | VRE | SKIN BACTERIA * | OTHER GRAM POSITIVES ** | GRAM NEG. RODS/ BACILLI *** | ENTERO-BACTER | C. DIFF | COLIFORMS NON-LACTOSE FERMENTERS **** | OTHERS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **SWEENEY 2009** | 68 computer terminals (keyboard + mice) | Total bacterial load | 67/68 (98.5%) showed some growth | | | 10/68 (14.7%) | | | | | | | | | |
| **TAN 2013** | Unknown number of keyboards (6 total samples) | Presence of MRSA, E. coli and K. pneumoniae resistant to third-gen cephalosporins, CRAB, VRE. | 6/6 (100%) | | 6/6 (100%) | | | 0/6 (0%) | | | Ceph-R Klebsiella spp. 0/6 (0%) | | | CRAB: 1/6 (17%) | |
| **TROCHESS-ET 2012** | Unknown number of keyboards and mice | Detection of S. aureus | | K: 4/47 (8.5%) M: 0/4 (0%) | | | | | | | | | | | |
| **WAGHORN 2005** | 48 keyboards | Total bacterial load (especially S. aureus, hemolytic strepto-cocci, P. aeruginosa and C.diff) | 100% grew organisms of some kind. 79% grew either moderate or heavy numbers of organisms. | | 1/48 (2%) | | | | 46/48 (96%) | | 12/48 (25%) | | 1/48 (2%) | 0 | Misc (including: Bacillus sp, fungal): 25/48 (52%) |
| **WESTERWAY 2017** | 10 ultra-sound keyboards | Total bacterial load | 100% of samples had 10 or more colonies (highest level of contamination) | | | | 3/10 (30%) | | | | | | | 7/10 (70%) | |

| AUTHOR, YEAR | DEVICE AND NUMBER | OUTCOME MEASURES | OVERALL BASELINE CONTAMINATION PREVALENCE | ALL S. AUREUS | MRSA | MSSA | ENTERO-COCCI: NON-VRE, OR NOT SPECIFIED | VRE | SKIN BACTERIA * | OTHER GRAM POSITIVES ** | GRAM NEG. RODS/ BACILLI *** | ENTERO-BACTER | C. DIFF | COLIFORMS NON-LACTOSE FERMENTERS **** | OTHERS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **WILSON 2006** | 17 keyboards (51 total samples) | Total bacterial load | 100% contaminated with at least one species. | | 11/51 (21%) | 3/51 (5.9%) | | | CNS: 51/51 (100%) Bacillus: 47/51 (92%) | | 30/51 (59%) | | | | |
| **XU 2017** | Unknown number of keyboards and mice | Detection of MRSA | 7/19 (36.8%) swabs positive for MRSA. | | 7/19 (36.8%) | | | | | | | | | | |

* Skin bacteria includes: (S. epidermidis, CNS, S. Caprae, diptheroids, Micrococcus, Bacillus, Kytococcus, Corynebacter, Propionibacteria, kocuria varians)
** Gram positives: Alpha-hemolytic strep, Streptococci, Sphingomonas
***Gram negative rods/bacilli includes: (E.coli, Klebsiella, Serratia)
**** Coliforms non-lactose fermenters: (Pseudomonas, Proteus, Acinetobacter, Citrobacter)

Abbreviations: A. baumannii = Acinetobacter baumannii, ACC = Aerobic Colony Counts, C. Diff = Clostridium difficile, CFU = Colony forming units, CNS = Coagulase-negative staphylococcus, CRAB = Carbapenem-resistant Acinetobacter baumannii, E. Coli = Escherichia coli, GNB = Gram Negative Bacilli, MRSA = Methicillin-resistant Staphylococcus aureus, MRSP = Methicillin-resistant Staphylococcus pseudintermedius, MSSA = Methicillin-sensitive Staphylococcus aureus, MSSE = Methicillin-sensitive Staphylococcus epidermidis, MSSH = Methicillin-sensitive Staphylococcus hyicus, MSSW = Methicillin-sensitive Staphylococcus warneri, NF-GNR = Non-Fermenting Gram-Negative Rods, ORSA = Oxacillin-resistant Staphylococcus aureus, OSSA Oxacillin-sensitive Staphylococcus aureus, P. aeruginosa = Pseudomonas aeruginosa, PCA = Plate count agar, S. aureus = Staphylococcus aureus, S. caprae = Staphylococcus caprae, S.D. = Standard deviation, S. epi = Staphylococcus epidermidis, VRE = Vancomycin-resistant Enterococcus

## Supplementary File 8: Studies reporting interventions without statistically significant reductions in contamination of computer peripherals or had unclear effectiveness outcomes

| STUDY | OUTCOME MEASURES | INTERVENTION METHOD | BASELINE CONTAMINATION | POST-INTERVENTION CONTAMINATION | P-VALUES | COMMENTS |
|---|---|---|---|---|---|---|
| **CORDEIRO 2015** | Total bacterial load | Computer keyboards were cleaned on a daily basis with a brush for removing dust. | 6/6 (100%) | All 6/6 contained Non-specified coagulase negative Staphylococcus post cleaning with dust brush. | Not reported | *No statistical significance of these changes reported* |
| **DANCER 2009** | Detection of S. aureus species (MSSA and MRSA), overall aerobic colony counts (ACC) | Enhanced cleaning: an additional cleaner was added to the ward and trained to clean hand-touch sites 1-3x/day Monday to Friday. | | Enhanced cleaning was associated with a 32.5% reduction in levels of microbial contamination at hand touch sites (results not specific to keyboards) MRSA was isolated from 1 keyboard during intervention phase. | P < 0.0001: 95% CI 23.2%, 42.9% (for all hand touch sites including keyboards) | *Statistically significant reduction in contamination, but results not specific to keyboards* |
| **DE GROOD 2012** | Total bacterial load | CaviWipes (a quaternary ammonium compound) with isopropanol) | 2 studies:<br>1) Pre/Post with 230 keyboards: 229/230 (99.6%) contaminated with CNS, Micrococcus spp., diptheroids, Bacillus spp. or alpha streptococci and 67% total keyboards positive with solid agar and broth any one cultures (MSSA, MRSA, Enterococcus (non VRE and VRE), GNB, C. diff., Yeast, fungus)<br>2) Cleankeys keyboards: 10/10 (100%) | 1) 35/230 (15.2%) still positive for pathogenic organisms, including 3 with C. diff.<br>2) 0/10 (0%) positive for pathogenic organisms. | Not reported | *No statistical significance of these changes reported* |
| **DUMFORD 2009** | Detection of C. difficile | Disinfection with bleach | 9/32 (28%) keyboards were contaminated with C. diff. | 4/25 (16%) keyboards and 0/1 mouse were contaminated with C. diff. | P = 0.18, but this is for all surfaces tested, not only keyboards | *Statistically significant reduction in contamination, but results not available for keyboards separately* |
| **GRABSCH 2012** | Detection of VRE | Hospital wide program including 'Bleach-Clean': replace surface cleaners with sodium hypochlorite solution plus Chloradet detergent; install | 1/9 swabs were VRE positive (11%) | Decreased in Period B: 1/78 (1.3%) swabs positive | P = 0.012 for reduction of all environmental contamination, not specific to keyboards | *Statistically significant reduction in contamination, but results not available for* |

| STUDY | OUTCOME MEASURES | INTERVENTION METHOD | BASELINE CONTAMINATION | POST-INTERVENTION CONTAMINATION | P VALUES | COMMENTS |
|---|---|---|---|---|---|---|
| | | cleaner dispensing stations, employment of cleaning supervisors and training program for cleaning staff, performance appraisals, modify protocols for managing VRE-colonized patients, thrice annual schedule of "super clean disinfection" | | | | *keyboards separately* |
| **JUNGNICKEL 2014** | Total bacterial load | Isopropanol wipes using the 6-step disinfection process guided by the deBac-app. | 2,033 CFU in total were counted on the 5 devices before disinfection during the four week monitoring period:<br>Gram positive: 1,950 CFU<br>Gram negative: 83 CFU | Decreased to a total of 87 CFU found on the devices during the four week monitoring period:<br>gram positive: 86 CFU<br>gram negative: 1 CFU | | *No statistical significance of these changes reported* |
| **MORTER 2011** | Detection of Norovirus | Actichlor plus solution | Not reported | After cleaning, NoV was detected on 4/10 (40%) of keyboards and 1/8 (12.5%) of mice.<br><br>After a second cleaning, 1/4 (25%) of keyboards remained positive and 0/3 (0%) of mice remained positive. | | *No baseline level of contamination, therefore change cannot be determined. However, even after first cleaning, 40% of keyboards were contaminated, suggesting poor effect* |
| **SMITH 2006** | Total bacterial load | Clorox disinfecting wipes | 52/120 (43%) of cultures positive, but significant pathogens were found in only 1.7% of cultures (MSSA and Serratia species) | 18/46 (39%) of cultures were positive for various organisms, but no significant pathogens were isolated | P 0.799 | *Non-statistically significant reduction in contamination* |
| **STAMBAUGH 2009** | Detection of Multidrug-resistant organisms | Disinfectant wipes (ammonium chloride and isopropyl alcohol) | Overall rate not given | Both conventional and sealed keyboard/mice experienced a reduction in detectable organisms when disinfected 3x/day.<br>CNS: reduced from 88.6% in baseline to 5% in sealed keyboards and 25% in conventional keyboards. | | *No statistical significance of these changes reported* |

| STUDY | OUTCOME MEASURES | INTERVENTION METHOD | BASELINE CONTAMINATION | POST-INTERVENTION CONTAMINATION | P VALUES | COMMENTS |
|---|---|---|---|---|---|---|
| | | | | Lactose fermenting GNR reduced from 25% in baseline to 10% in sealed keyboards and 0% in conventional. Bacillus reduced from 23% in baseline to 10% in sealed keyboards and 0% in conventional keyboards<br>All other organisms were reduced 100% | | |
| **SWEENEY 2009** | Total bacterial load | Astroplast Nano-UV disinfectant light scanner | 67/68 (98.5%) showed some growth | 62/68 (91%) showed some growth after disinfection | | *No statistical significance of these changes reported* |

Abbreviations: ACC = Aerobic Colony Counts, C. Diff = Clostridium difficile, CFU = Colony forming units, CNS = Coagulase-negative staphylococcus, GNB = Gram Negative Bacilli, GNR = Gram Negative Rods, MRSA = Methicillin-resistant Staphylococcus aureus, MSSA = Methicillin-sensitive Staphylococcus aureus, NoV = Norovirus, VRE = Vancomycin-resistant Enterococcus

## Supplementary File 9: Studies reporting the effect of decontamination interventions on patient infection rates

| STUDY | STUDY DESIGN | INTERVENTION METHOD | EFFECT ON INFECTION OR COLONIZATION RATE |
|---|---|---|---|
| **DANCER 2009** | Prospective Cross-over | Enhanced cleaning: an additional cleaner was added to the ward and trained to clean hand-touch sites 1-3 times per day | Reduction in rate of new MRSA infections from 9 of 327 MRSA patient days during normal cleaning, to 4 of 475 patients days during enhanced cleaning, a reduction of 26.6% (95% CI 7.7%, 92.3%) (P=0.032). |
| **GRABSCH 2012** | Pre-Post | Hospital wide program including 'Bleach-Clean' | 24.8% reduction in newly recognized VRE colonizations: 208/1948 patients screened vs 324/4035, (P = 0.001). |
| **NEELY 1999** | Pre-Post | All personnel required to wear gloves before using the computer and removed before leaving the room, plus a defined daily cleaning procedure for plastic keyboard covers provided to housekeeping staff | 13 acquired colonizations and 16 total colonizations in the 5 months pre-intervention vs. 4 acquired colonizations and 14 total colonizations of Acinetobacter baumannii in the 7 months post-intervention (p <0.05). |
| **RASTOGI 2012** | Cross sectional taken biweekly for 1 year | During the study period, blood, respiratory, and cerebrospinal fluid cultures from admitted NICU patients were sent if clinically indicated. If positive, they were temporally correlated with the matching surveillance cultures. | 6 of the 48 (12.5%) positive blood cultures matched the organism growing from the surveillance sites, but the correlation was not significant (P=0.076).<br>None of the 31 positive respiratory cultures, nor the single positive cerebrospinal fluid culture correlated to organisms grown from the NICU environment. |
| **WILSON 2011** | Prospective randomized cross-over | Enhanced cleaning of hand contact surfaces - trained hygiene technicians performed an extra twice daily cleaning using cloths soaked in a copper-based biocidal formulation. | No effect on incidence of patient acquisition of MRSA (OR, 0.98; 95% CI, 0.58– 1.65; p = 0.93) |

Abbreviations: MRSA = Methicillin-resistant Staphylococcus aureus, VRE = Vancomycin-resistant Enterococcus

| | Objectives | | Sample Selection | | | | Detection methods | Outcome Measures | | | Confounding |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Is the aim/objective of the study clearly described? | Was the ideal study design chosen to meet the aims? | Were selection criteria for the devices pre-specified, clearly described, and implemented consistently? | Were the devices in the study representative of the general or clinical population of interest? | Was the number of examined items stated and/or an inclusion rate given? | Was a power calculation prespecified to guide sample size? | Were the swabbing and lab processes clearly stated and consistently performed across all devices? | Were the outcomes measured at multiple time points? | Were findings for all primary outcomes reported? | Are the estimates of prevalence or incidence given with confidence intervals and in detail by subgroup, if appropriate? | Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)? |
| Al-Hamad 2008 | Yes | Yes (Cross sectional) | No | Yes | No | No | Yes | Yes | Yes | No | Unclear |
| Ali 2015 | Yes | Yes (Cross sectional) | Yes | Yes | No | No | Yes | No | Yes | No, but gives Mean no. of CFU/cm² ± SD | Some Compared sampling techniques: contact plate vs. Sponge swab |
| Anastasiades 2009 | Yes | Yes (Cross sectional) | No | Yes | Yes | No | Yes | Yes | Yes | No | No |
| Bures 2000 | Yes | Unclear (unclear if items were swabbed each time) | Yes | Yes | Yes | No | Yes | Yes | Yes | No | Unclear |
| Catano 2012 | Yes | Yes (Cross sectional) | No | Yes | Yes | No | Yes | No | Yes | No | No |
| Choi 2014 | Yes | Yes (Cross sectional) | No | Yes | Yes | No | No | Mixed/Unclear | Yes | No | No |
| Ciragil 2005 | Yes | Yes (Cross sectional) | No | Yes | Yes | No | Yes | No | Yes | No | No |
| Dancer 2008 | Yes | Yes (Cross sectional, 1x week for 6 months per ward) | Yes | Yes | Yes | No | Yes | Yes | Yes | No | Yes |
| Devine 2001 | Yes | Unclear design (possibly cross-sectional) | No | Yes | Yes | No | yes | No | Yes | No | No |

| | Objectives | | Sample Selection | | | | Detection methods | Outcome Measures | | | Confounding |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Is the aim/objective of the study clearly described? | Was the ideal study design chosen to meet the aims? | Were selection criteria for the devices pre-specified, clearly described, and implemented consistently? | Were the devices in the study representative of the general or clinical population of interest? | Was the number of examined items stated and/or an inclusion rate given? | Was a power calculation prespecified to guide sample size? | Were the swabbing and lab processes clearly stated and consistently performed across all devices? | Were the outcomes measured at multiple time points? | Were findings for all primary outcomes reported? | Are the estimates of prevalence or incidence given with confidence intervals and in detail by subgroup, if appropriate? | Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)? |
| Engelhart 2008 | Yes | Yes (Cross sectional) | No | Yes | Yes | No | Yes | No | Yes | No Gives mean, median CFU values | Yes (# of users, ward vs. ICU, time used before sampling, room type) |
| Faires 2012 | Yes | Yes (Multiple cross sectional samples) | Yes | Yes | No | No | Yes | Yes | Yes | No - CI given only for total rate of all surfaces sampled | Yes (surface location, type of surface, hospital (3 studied) |
| Faires 2013 | Yes | Mixed - Cross sectional yes for prevalence aim but not for determining risk factors association | No (for keyboards) | Yes | No | No | Yes | Yes | Yes | No | No |
| Farias 2017 | Yes | Yes (Cross sectional) | Unclear (text states items were sampled from each ward, but results only show keyboards in one ward) | Yes | Yes | No | Yes | Yes | Yes | No | No (not specific to keyboards) |
| Fellowes 2006 | Yes | Yes (Cross sectional) | No | Yes | Yes | No | Yes | No | Yes | No | No |
| Gerba 2016 | Yes | Yes (Cross sectional) | No | Unclear | Yes | No | Yes | No | Yes | No | No |
| Gray 2007 | No | Yes (Cross sectional) | No | Yes | Yes | No | Yes | Yes | Yes | No | Yes (any significant differences in the # of colonies from the 3 areas sampled) |

| | Objectives | | Sample Selection | | | | Detection methods | Outcome Measures | | | Confounding |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Is the aim/objective of the study clearly described? | Was the ideal study design chosen to meet the aims? | Were selection criteria for the devices pre-specified, clearly described, and implemented consistently? | Were the devices in the study representative of the general or clinical population of interest? | Was the number of examined items stated and/or an inclusion rate given? | Was a power calculation prespecified to guide sample size? | Were the swabbing and lab processes clearly stated and consistently performed across all devices? | Were the outcomes measured at multiple time points? | Were findings for all primary outcomes reported? | Are the estimates of prevalence or incidence given with confidence intervals and in detail by subgroup, if appropriate? | Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)? |
| Hardy 2014 | Yes | Yes, for contamination aim (Cross sectional) | Yes | Yes | No | No | Yes | Yes | Yes | No | No |
| Hartman n 2004 | Yes | Yes (Cross sectional over 3 months) | No | Yes | No | No | Yes | Yes | Yes | No | Yes (patient room vs. physician's station, patient room vs central workstation) |
| Hassan 2014 | Yes | Yes (Cross sectional) | No | Unclear | Yes | No | No | No | Yes | No | Yes (single user vs. multiple user) |
| Hirsch 2014 | Yes | Yes (Cross sectional) | Yes | Yes | Yes | No | Yes | No | Yes | Yes | Yes (hospital vs. non-hospital setting) |
| Hong 2012 | Yes | Yes (Cross sectional) | Yes | Yes | Yes | Yes | Yes | No | Yes | Yes | No (hand hygiene and contact studied, but not statistically adjusted for relationship to contamination) |
| Karbasiz ade 2014 | Yes | Yes (Cross sectional) | No | Unclear | Yes | Yes | Yes | No | Yes | No | No |
| Keerasu ntonpon g 2017 | Yes | Yes (Cross sectional) | No | Yes | Yes | No | Yes | No | Yes | No | Yes (compared patient areas vs. offices) |
| Khan 2015 | Yes | No (Cross sectional) | No | No | Yes | No | Yes | No | Unclear - some findings reported but data not shown. | No | Mixed - some data not shown at one institution, differences between specialties |

| | Objectives | | Sample Selection | | | | Detection methods | Outcome Measures | | | Confounding |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Is the aim/objective of the study clearly described? | Was the ideal study design chosen to meet the aims? | Were selection criteria for the devices pre-specified, clearly described, and implemented consistently? | Were the devices in the study representative of the general or clinical population of interest? | Was the number of examined items stated and/or an inclusion rate given? | Was a power calculation prespecified to guide sample size? | Were the swabbing and lab processes clearly stated and consistently performed across all devices? | Were the outcomes measured at multiple time points? | Were findings for all primary outcomes reported? | Are the estimates of prevalence or incidence given with confidence intervals and in detail by subgroup, if appropriate? | Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)? |
| Kiedrowski 2013 | Yes | Yes (Cross sectional) | No | Unclear | Yes | No | No | No | No S. aureus reported but not MRSA | No | No |
| Link 2016 | Yes | Yes (Cross sectional with a control) | Yes | Yes | No (only # of samples) | Yes (for # of samples) | Yes | Yes | No | No | Yes (high touch vs. low touch areas, minutes of surgery) |
| Lu 2009 | Yes | Yes (Cross sectional) | No | Yes | Yes | No | Yes | No | Yes | No | Yes (non-ICU vs. ICU, accounting vs. clinical use) |
| Malta 2016 | Yes | Yes (Cross sectional at 2 time points) | Yes | Yes | No | No | Yes | Yes | Yes | No (but mean, med, min, max given) | Some (before/after clinical procedures) |
| Man 2002 | Yes | Yes (Cross sectional) | No | Yes | Yes | No | Yes | No | Yes | No | No |
| Moore 2013 | Yes | Yes (Cross sectional over 17 weeks) | Yes | Yes | Unclear | No | Yes | Yes | Unclear - not all results reported for keybands (only in one ward) | No | Some - zones of distance from patient |
| Motta 2007 | Yes | Yes (Cross sectional at 3x/day 1x/month over 1 year) | Yes | Yes | Yes | No | Yes | Yes | Yes | Yes, but overall baseline rate not stated, only by subgroup | Some (samples taken before, during, and after clinical procedures) |
| Oguzkaya-Artan 2015 | Yes | Yes (Cross sectional) | No | Yes | Yes | No | No | No | Yes | No | No |
| Oie 2005 | Yes | Yes (Cross sectional) | No | Yes | Yes | No | Yes | Yes | Yes | No (but mean SD given) | No |
| Otter 2011 | Yes | Yes (Cross sectional) | No | Yes | No | No | Yes | No | Yes | No | No |

| | Objectives | | Sample Selection | | | | Detection methods | Outcome Measures | | | Confounding |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Is the aim/objective of the study clearly described? | Was the ideal study design chosen to meet the aims? | Were selection criteria for the devices pre-specified, clearly described, and implemented consistently? | Were the devices in the study representative of the general or clinical population of interest? | Was the number of examined items stated and/or an inclusion rate given? | Was a power calculation prespecified to guide sample size? | Were the swabbing and lab processes clearly stated and consistently performed across all devices? | Were the outcomes measured at multiple time points? | Were findings for all primary outcomes reported? | Are the estimates of prevalence or incidence given with confidence intervals and in detail by subgroup, if appropriate? | Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)? |
| Phumisantiphong 2009 | Yes | No (Cross sectional) | Yes | Yes | Yes | No | No | No | Yes | No | No |
| Pugliese 2011 | Yes | Yes (Cross sectional) | No | Unclear | Yes | No | No | No | Yes | No | Some (specific keyboard location) |
| Rastogi 2012 | Yes | Unclear (Cross sectional taken biweekly for 1 year) | Yes | Yes | Yes | No | Yes | Yes | Yes | No | No (did study temporal association of positive blood cultures with positive surveillance cultures) |
| Reem 2014 | Yes | Yes (Cross Sectional, quarterly for 1 year) | Yes | Yes | Yes | No | No (not specified which of the 2 swabbing methods was used on keyboards) | Yes | Yes | No | No |
| Richard 2017 | Yes | Yes (Cross sectional) | Yes | Yes | Yes | No | Yes | No | Yes | No (RLU mean, SD, min/max given) | No but compared keyboards to contamination on other surfaces |
| Rutala 2006 | Yes | Yes (Cross sectional) | No | Yes | Yes | No | Yes | No | Yes | No | No (CFU range given) |
| Saito 2015 | Yes | Yes (Cross sectional) | No | Yes | Yes | No | Yes | No | Yes, but not always specific by subgroup | No (ATP mean value and SD given) | Yes, but these results specific to keyboards not provided |
| Schultz 2003 | Yes | Yes (Cross sectional) | Yes | Yes | Yes | No | Yes | No | Yes | No | No |

| | Objectives | | Sample Selection | | | | Detection methods | Outcome Measures | | | Confounding |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Is the aim/objective of the study clearly described? | Was the ideal study design chosen to meet the aims? | Were selection criteria for the devices pre-specified, clearly described, and implemented consistently? | Were the devices in the study representative of the general or clinical population of interest? | Was the number of examined items stated and/or an inclusion rate given? | Was a power calculation prespecified to guide sample size? | Were the swabbing and lab processes clearly stated and consistently performed across all devices? | Were the outcomes measured at multiple time points? | Were findings for all primary outcomes reported? | Are the estimates of prevalence or incidence given with confidence intervals and in detail by subgroup, if appropriate? | Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)? |
| Senok 2015 | Yes | Unclear | No | Yes | No | No | Nes | No | Yes | No | No |
| Sykes 2006 | Yes | Yes, for the prevalence aim (Cross Sectional - 15x over 3 months) | No | Yes | Yes | No | Yes | Yes | Overall cont. rate not given for keyboards - isolated pathogens listed | No | No |
| Tan 2013 | Yes | Yes, for the prevalence aim (Cross Sectional) | No | Yes | No | No | Yes | No | Yes | No | No |
| Trochesset 2012 | Yes | Yes (Cross sectional) | No | Yes | No | No | Unclear (not clear how many times each object was sampled) | Yes | Yes | No | Yes, some looked at # of positive sites for S. aureus at different dates and at personal vs nonpersonal surfaces |
| Waghorn 2005 | Yes | Yes (Cross sectional) | No | Yes | Yes | No | Yes | No | Yes | No | No |
| Westerway 2017 | Yes | Yes (Cross sectional) | No | Yes | Yes | No | Yes | No | Yes | No | No |
| Wilson 2006 | Yes | Yes (Cross sectional) | Yes | Yes | Yes | No | Unclear (number of swabs varied because some patients were discharged or died) | Yes | Yes | No (but median and range of CFU given) | No |
| Yun 2012 | Yes | Yes (Cross sectional) | No | Yes | Unclear if # is samples or keyboards/ mice | No | Yes | No | Yes | No | No |

| | Objectives | | Sample Selection | | | | | Intervention | |
|---|---|---|---|---|---|---|---|---|---|
| | Is the aim/objective of the study clearly described? | Was the ideal study design chosen to meet the aims? | Were selection criteria for the devices pre-specified, clearly described, and implemented consistently? | Were the devices in the study representative of those who would be eligible for the intervention in the general or clinical population of interest? | Was the number of examined items stated and/or an inclusion rate given? | Was a power calculation prespecified to guide sample size? | Was loss to follow-up after baseline 20% or less? | Was the intervention clearly described and delivered consistently across the study population? | Was the timeframe appropriate so that one could reasonably expect to see an association between exposure and outcome if it existed? |
| Albrecht 2013 | Yes | Yes (Prospective comparative analysis) | Yes | Yes | Yes | Yes | Yes | No | Yes |
| Codish 2015 | Yes | Yes (Cluster RCT) | No | Yes | Yes | No | Yes | Yes | Yes |
| Cordeiro 2015 | Yes | No (Pre/Post) | No | Yes | Yes | No | Yes | No | Yes |
| Dancer 2009 | Yes | Yes (Prospective Cross-over) | Yes | Yes | Yes | Yes | Unclear | Yes | Yes |
| de Grood 2012 | Yes | No (Cross sectional + Pre/Post) | Yes | Yes | Yes | No | Yes | Yes | Yes |
| Dumford 2009 | No - aims do not mention the post-cleaning survey | No (Cross sectional + Pre/Post) | Yes | Yes | Yes | No | No - not all keyboards were used in -post study | No | Yes |
| Duszak 2014 | No - aims do not mention the post-cleaning survey | Mixed… (Cross sectional + Pre/Post) | No, clearly described but not consistently implemented | Yes | Yes | No | No - not all keyboards were used in -post study | Mixed - clearly described but not delivered to all keyboards in initial sample | Yes |
| Fukada 2008 | Yes | No (Pre/Post) | No | Yes | No | No | No - not all keyboards were used in -post study | Mixed - clearly described but not delivered to all keyboards in initial sample | Yes |
| Gostine 2016 | Yes | No? (Pre/Post) | Yes | Yes | Yes | No | Yes | Yes | Unclear (study explored range of types of disinfection cycles and time delays) |
| Grabsch 2012 | Yes | No (Pre/Post) | No | Yes | No | No | Unclear - looks like there were more sites during intervention | Yes | Unclear (poorly described) |
| Jones 2015 | Yes | Yes (Controlled Trial) | Yes | Yes | Yes | No | Yes | Yes | Yes |

| | Comparison/Controls | | Detection Methods | | Outcome Measures | | | | Confounding |
|---|---|---|---|---|---|---|---|---|---|
| | Was there a comparison or control group? | If yes, explain what the comparison was. | Were the outcome assessors (swabbing and lab) blinded to the intervention or exposure status of participants? | Were the swabbing and lab processes clearly stated and consistently performed across all devices? | Were the outcome measures pre-specified, clearly defined, valid, reliable, and assessed consistently using reliable methods across all devices? | Was the outcome measured multiple times before the intervention and multiple times after the intervention? (Or were multiple samples taken from each intervention group?) | Were findings for all primary outcomes reported? | Did statistical methods examine changes in outcome measures from before to after the intervention? Were statistical tests done that provided p values for the pre-to-post changes? | Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)? |
| Albrecht 2013 | No | | Yes | Yes | Yes | No | Yes | Yes | Unclear |
| Codish 2015 | Yes | 1 group disinfected with Mediwipes, another with TriGene wipes | Unclear | Yes | Yes | No | Yes | Yes | Unclear |
| Cordeiro 2015 | Yes | Pre and post samples compared. | Unclear | Yes | No | No | No | No | No |
| Dancer 2009 | Yes | Two matched wards selected, the intervention conducted 6 months in one, then 6 months in the other | Unclear | Yes | Yes | Yes | Yes - but baseline specific to keyboards not given | Yes | No |
| de Grood 2012 | Yes | CleanKeys keyboard vs. conventional keyboards | Unclear | Yes | Yes | No - twice before cleaning, once after | Yes | No | No |
| Dumford 2009 | Yes | A sample of surfaces were sampled again 14 months after initial survey (after a disinfection protocol was initiated) | Unclear | Yes | Yes | No | Yes | Yes, but for all surfaces tested, not only keyboards | No |
| Duszak 2014 | Yes | At 1 workstation in each of the 4 reading rooms, sampling was repeated after being disinfected. | Unclear | Yes | Yes | No | Yes | Yes (but not for keyboards separately) | No |
| Fukada 2008 | Yes | Keyboards in the OR were swabbed after health procedure vs. 1 hour after cleaning | Unclear | Yes | Yes | No | Yes | Yes | No |
| Gostine 2016 | Yes | Keyboards tested prior to cleaning vs. keyboards disinfected using UV Angel lamps | Unclear | Mixed: Swabbing process defined, but not lab | Yes | Yes | Yes | Yes | No, but effect of UV cycle length and delay options reported |
| Grabsch 2012 | Yes | Outcomes were assessed during the 6 months pre and 12 months post implementation | Unclear | No, swabbing timing not clear or done consistently throughout pre-period | Yes | Yes | Yes | Yes, but for all surfaces tested, not only keyboards | No |
| Jones 2015 | Yes | In ICU: Pre and post swabs with both CHG spray and stadard methods<br>In wards: Swabs taken before and after CHG intervention | Mixed: lab persons blinded only | Yes | Yes | Yes | Yes | Yes | No |

| | Objectives | | Sample Selection | | | | | Intervention | |
|---|---|---|---|---|---|---|---|---|---|
| | Is the aim/objective of the study clearly described? | Was the ideal study design chosen to meet the aims? | Were selection criteria for the devices pre-specified, clearly described, and implemented consistently? | Were the devices in the study representative of those who would be eligible for the intervention in the general or clinical population of interest? | Was the number of examined items stated and/or an inclusion rate given? | Was a power calculation prespecified to guide sample size? | Was loss to follow-up after baseline 20% or less? | Was the intervention clearly described and delivered consistently across the study population? | Was the timeframe appropriate so that one could reasonably expect to see an association between exposure and outcome if it existed? |
| Jungnickel 2014 | Yes | No (Pre/Post) | No | Yes | Yes | No | Yes | Unclear - disinfection process done "as (care staff) saw fit" | Yes |
| Martin 2011 | Yes | Yes (Randomized double blind cross-over trial) | Yes | Yes | Yes | No | Yes | Yes | Yes |
| Messina 2013 A | Yes | No (Pre/Post) | Yes | Yes | Yes | No | Yes | Yes | Yes |
| Messina 2013 B | Yes | No (Pre/Post) | Yes | Yes | Yes | No | Yes | Yes | Yes |
| Morter 2011 | Yes | No (Post-Intervention survey) | Yes | Unclear (Only conducted where there were NoV outbreaks) | Yes | No | Unclear | Yes | Yes |
| Neely 1999 | No | No (Pre/Post) | No | Yes | No | No | Unclear | Yes | Yes |
| Patel 2010 | Yes | No (Cross sectional + Pre/Post) | No | Yes | Yes | No | No - only 2 keyboards were used in post interv. study | Yes | Yes |
| Shaikh 2016 | Yes | No (Pre/Post) | No | Unclear | Yes | No | Yes | Yes | Yes |
| Smith 2006 | Yes | No Pre/Post | Yes | Yes | Yes | No | No - not all keyboards were used in -post study | No | Yes |
| Stambaugh 2009 | Yes | No Pre/post with stratfied groups | Yes | Yes | Yes | No | No - not all keyboards were used in -post study | Yes | Yes |
| Sweeney 2009 | Yes | No (Pre/Post) | No | Yes | Yes | No | Yes | Yes | Yes |
| Wilson 2008 | Yes | Yes (Controlled trial) | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Wilson 2011 | Yes | Yes (Prospective randomized cross-over) | Yes | Yes | No | No | Yes | Yes | Standard vs. enhanced cleaning |
| Xu 2017 | Yes | No (Pre/Post) | No | yes | No | No | much higher in interv. than | Yes | Yes |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | baseline (19 v. 206 samples) | | |
| | **Comparison/Controls** | | **Detection Methods** | | **Outcome Measures** | | | | **Confounding** |
| | Was there a comparison or control group? | If yes, explain what the comparison was. | Were the outcome assessors (swabbing and lab) blinded to the intervention or exposure status of participants ? | Were the swabbing and lab processes clearly stated and consistently performed across all devices? | Were the outcome measures pre-specified, clearly defined, valid, reliable, and assessed consistently using reliable methods across all devices? | Was the outcome measured multiple times before the intervention and multiple times after the intervention? (Or were multiple samples taken from each intervention group?) | Were findings for all primary outcomes reported? | Did statistical methods examine changes in outcome measures from before to after the intervention? Were statistical tests done that provided p values for the pre-to-post changes? | Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)? |
| Jungnickel 2014 | Yes | Samples taken before and after intervention | Unclear | No | Yes | Yes | Yes | No | No |
| Martin 2011 | Yes | UV light treated keyboards vs. Existing keyboards vs. non-UV control keyboards | Yes | Yes | Yes | No | Yes | Yes | Yes, some |
| Messina 2013 A | Yes | Pre-and post disinfection samples taken | Unclear | Yes | Yes | No | Yes | Yes | Yes, some such as type of clinical setting |
| Messina 2013 B | Yes | Pre-and post disinfection samples taken | Unclear | Yes | Yes | No | Yes | Yes | No |
| Morter 2011 | No | | Unclear | Yes | Yes | No | Yes | No | No |
| Neely 1999 | Yes | A. baumannii colonizations pre and post infection control measures | Unclear | Unclear | No | N/A | N/A | Yes | No |
| Patel 2010 | Yes | 2 of the keyboards were swabbed after being disinfected twice daily | Unclear | Yes | No (only did aerobic cultures not anerobic too) | No | Yes | Yes | No |
| Shaikh 2016 | Yes | keyboards swabbed before and after UV decontamination | Unclear | Yes | Yes | No | Yes | Yes | No |
| Smith 2006 | Yes | Swabs from desktop computers in hallway were compared with physician notebooks. Also, some notebooks compared pre/post cleaning | No | Yes | Yes | No | No | Yes | No |
| Stambaugh 2009 | Yes | 3 groups:<br>- not disinfected<br>- conventional keyboards disinfected 3x/day<br>- Sealed keyboards disinfected 3x/day | Unclear | Yes | Yes | Yes | Yes | No | No |
| Sweeney 2009 | Yes | Devices swabbed before and after disinfection | Unclear | Yes | Yes | No | Yes | No | No |
| Wilson 2008 | Yes | 2 types of test keyboards vs. standard control keyboard | Unclear | No | Yes | Yes | Yes | Yes | No |
| Wilson 2011 | Yes | Yes | Unclear | Yes | Yes | Yes | Unclear for keyboards | Unclear for keyboards | Mostly no (timing of sampling assessed, seasons) |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Xu 2017 | Yes | Baseline period: daily routine cleanings vs. Intervention period using 2 types of disinfectant wipes | Unclear | Yes | Yes | Yes | No | Yes | No |