How long can nosocomial pathogens survive on textiles? A systematic review

Wie lange können nosokomiale Infektionserreger auf Textilien überleben? Eine systematische Übersichtsarbeit

Abstract

Aims: Healthcare-associated infections linked to contaminated textiles are rare but underline their potential role as a source for transmission. The aim of the review was to summarize the experimental evidence on the survival and persistence of the different types of nosocomial pathogens on textiles.

Methods: A literature search was performed on MedLine. Original data on the survival of bacteria, mycobacteria, and fungi and persistence of viruses on textiles were evaluated.

Results: The survival of bacteria at room temperature was the longest on polyester (up to 206 days), whereas it was up to 90 days for some species on cotton and mixed fibers. Only low inocula of 100 CFU were found on all types of textiles with a short survival time of ≤3 days. Most bacterial species survived better at elevated air humidity. The infectivity of viruses on textiles is lost much faster at room temperature, typically within 2–4 weeks.

Conclusions: Contaminated textiles or fabrics may be a source of transmission for weeks. The presence of pathogens on the coats of healthcare workers is associated with the presence of pathogens on their hands, demonstrating the relevance of textile contamination in patient care.

Keywords: survival, pathogens, textiles, fabrics

Zusammenfassung

Zielsetzung: Nosokomiale Infektionen, die von kontaminierten Textilien ausgehen, sind selten, zeigen aber dennoch ihr Potenzial als Quelle einer Übertragung. Ziel der Übersichtsarbeit war es, experimentell gewonnene Daten zum Überleben bzw. zur Persistenz verschiedener nosokomialer Pathogene auf Textilien zusammenfassend darzustellen.

Methode: Eine Literaturrecherche wurde auf MedLine durchgeführt. Originaldaten zum Überleben von Bakterien, Mykobakterien und Pilzen sowie zur Persistenz von Viren auf Textilien wurden ausgewertet.

Ergebnisse: Das Überleben von Bakterien bei Raumtemperatur war am längsten auf Polyester (bis zu 206 Tage), wohingegen es auf Baumwoll- bzw. gemischten Fasern bis zu 90 Tage betrug. Nur kleine Inokula von 100 KBE konnten auf allen Textilien über maximal 3 Tage überleben. Die Mehrzahl der Bakterienspezies überlebte bei höherer Luftfeuchtigkeit besser. Die Infektiosität der Viren ging auf Textilien bei Raumtemperatur schneller verloren, meist innerhalb von 2–4 Wochen.

Fazit: Kontaminierte Textilien können über Wochen eine Quelle für Übertragungen darstellen. Der Nachweis von Pathogenen auf den Kitteln der Mitarbeiter war mit dem Nachweis der Pathogene auf ihren Händen assoziiert. Auch darin zeigt sich die Bedeutung der Kontamination von Textilien in der Patientenversorgung.

Schlüsselwörter: Überleben, Pathogene, Textilien, Stoffe
Introduction

Healthcare-associated infections linked to contaminated textiles are rare, but play a role as a potential source of transmission. One example is the spread of group A streptococcus infections. An outbreak on a geriatric medical ward was explained by the presence of one healthcare worker (HCW) on the ward who was perineal carrier. Contamination of a fabric-upholstered chair used by the HCW in an office adjacent to the ward was also detected and was suspected to have enhanced the transmission to other HCWs [1]. Another example is an outbreak of meropenem-resistant A. baumannii on an intensive care unit. The major source appeared to be the curtains surrounding the patient’s beds [2]. Feather pillows have been described as an unexpected source of Acinetobacter spp., potentially causing outbreaks [3]. Outbreaks caused by bacterial spores on linen have also been reported, e.g., resulting in bacteraemia [4], [5]. Work garments have also been described to be contaminated with various types of microorganisms. The cuffs of long-sleeved coats frequently contact patients or environmental surfaces [6]. Soiled linen was also described as the source of tinea corporis infections in two HCWs who had only indirect contact to a patient infected with T. tonsurans [7]. The survival of nosocomial pathogens on inanimate surfaces has been well described [8]. But the persistence of pathogens on different types of textiles has not been reviewed. The purpose of this review was therefore to summarize the experimental evidence on the survival and persistence of the different types of nosocomial pathogens on textiles.

Methods

A MedLine search was performed on the 29th and 31st of May, 2019. The following terms were used: cotton bacteria survival (361 hits), cotton virus survival (155 hits), cotton virus persistence (39 hits), cotton yeast survival (16 hits), cotton fungus survival (267 hits), cotton mycobacterium survival (19 hits), polyester bacteria survival (327 hits), polyester virus survival (57 hits), polyester virus persistence (8 hits), polyester yeast survival (13 hits), polyester fungus survival (174 hits), polyester mycobacterium survival (13 hits), wool bacteria survival (46 hits), wool virus survival (26 hits), wool virus persistence (8 hits), wool yeast survival (5 hits), wool fungus survival (31 hits), wool mycobacterium survival (5 hits), silk bacteria survival (51 hits), silk virus survival (14 hits), silk virus persistence (0 hits), silk yeast survival (6 hits), silk fungus survival (32 hits), and silk mycobacterium survival (0 hits). Publications were included and results were extracted from them when they provided original data on the survival or duration of persistence of bacteria, mycobacteria, fungi or viruses on textiles. Articles were excluded when they did not provide any original data on survival or persistence. Reviews were also excluded, but screened for any information within the scope of the review.

Results

Bacteria

Cotton

On cotton, many bacterial species are able to survive at room temperature for long periods of time, such as Enterococcus spp. (up to 90 d), P. aeruginosa (up to 8 w), S. aureus (up to 8 w), K. pneumoniae (up to 8 w), S. pyogenes (up to 46 d), E. coli (up to 45 d), Enterobacter spp. (up to 35 d), S. sonnei (up to 27 d), coagulase-negative Staphylococcus spp. (up to 27 d), Acinetobacter spp. (up to 25 d), P. mirabilis (up to 9 d) and S. maltophilia (up to 7 d). Other species at a high initial cell count, however, survive only for short periods of time at room temperature, e.g., N. gonorrhoeae and S. marcescens (both up to 3 d), B. fragilis, B. cepacia and C. diptheriae (all up to 2 d), P. vulgaris (up to 1 d), V. cholerae (up to 8 h), Salmonella spp. (up to 5 h), C. jejuni (up to 3 h) and F. nucleatum (up to 2 h). At lower temperatures, the survival may be longer, as shown for S. sonnei and S. equi. A low inoculum of approximately 100 CFU was found for many species with only a short survival period of 2 h (Acinetobacter spp.) or ≤1 h (E. coli, P. mirabilis, P. aeruginosa and S. marcescens). Only Enterobacter spp. was able to survive much longer (up to 3 d) when inoculated with only 100 CFU. M. bovis survived on cotton for 2 m. Higher air humidity was associated with longer survival of E. coli, whereas lower air humidity enhanced the survival of S. aureus and S. pyogenes (Table 1).

Synthetic fibers

On synthetic fibers such as polyester, the survival times of high inocula at room temperature ranged from up to 206 d (E. coli, S. aureus, S. pyogenes), 90 d (Enterococcus spp.), 56 d (K. pneumoniae, P. aeruginosa), 26 d (Enterobacter spp.), 14 d (Acinetobacter spp.) to 7 d (S. marcescens). A low inoculum of approximately 100 CFU was found for many species with only a short survival period of 2 d (K. pneumoniae), 1 d (Enterobacter spp.), 8 h (Acinetobacter spp.), 2 h (P. mirabilis) or ≤1 h (E. coli, P. aeruginosa, S. marcescens). Higher air humidity favored longer survival of E. coli, S. aureus and S. pyogenes (Table 2).

Mixed and other fibers

High inocula applied to mixed and other fibers were able to survive at room temperature for up to 90 d (Enterococcus spp.), 49 d (Enterobacter spp.), 45 d (E. coli), 41 d (S. aureus), 33 d (P. aeruginosa), 28 d (coagulase-negative Staphylococcus spp.), 19 d (Acinetobacter spp.), 14 d (K. pneumoniae, M. morganii, P. mirabilis), and 7 d...
Table 2: Survival of bacteria on synthetic fibers

| Species                  | Strains/isolates | Inoculum | Material | Temperature | Survival | Reference |
|--------------------------|------------------|----------|----------|-------------|----------|-----------|
| A. baumannii             | 15 multi-resistant strains | $10^2$–$10^9$ | Polyester | 25°C | ≥7 d | [24] |
| Acinetobacter spp.       | 2 isolates from a hospital (1 vanA VRE, 1 vanB VRE) | $10^2$–$10^5$ | Polyester | 22°C–26°C | 8 h to 4–14 d | [27] |
| Enterobacter spp.        | 2 isolates from a hospital (vanA VRE) | $10^2$–$10^5$ | Polyester | 22°C–26°C | 1 d to 5–26 d | [27] |
| E. casseliflavus         | 1 isolate from a hospital (vanC VRE) | $10^7$ | Polyester | 23°C–24°C | >90 d | [33] |
| E. faecalis              | ATCC 29212       | $10^7$ | Synthetic fibers | RT | 2 w | [34] |
| E. faecium               | 4 isolates from a hospital (1 vanA VRE, 1 vanB VRE) | $10^7$ | Polyester | 23°C–24°C | 73–90 d | [33] |
| E. faecium               | 15 multi-resistant strains | $10^5$–$10^6$ | Polyester | 25°C | ≥7 d | [24] |
| E. faecium               | 4 isolates from a hospital (vanA VRE, 1 vanB VRE) | $10^7$ | Polyester | 23°C–24°C | 43–90 d | [33] |
| E. gallinarum            | 1 isolate from a hospital (vanC VRE) | $10^7$ | Polyester | 23°C–24°C | >90 d | [33] |
| E. coli                  | 2 isolates from a hospital | $10^5$–$10^5$ | Polyester | 22°C–26°C | 1 h to 3–9 d | [27] |
| E. coli                  | NCTC 8003        | $10^8$ | Polyester | 23°C | <10 d | [36] |
| E. coli                  | ATCC 35218       | $10^7$ | Synthetic fibers | RT | 3 w | [34] |
| E. coli                  | NCTC 8545        | $10^5$–$10^6$ | Polyester | RT | 46–206 d* | [35] |
| K. pneumoniae            | 2 isolates from a hospital | $10^2$–$10^5$ | Polyester | 22°C–26°C | 2 d to 4–11 d | [27] |
| K. pneumoniae            | 15 multi-resistant strains | $10^5$–$10^6$ | Polyester | 25°C | <3 d | [24] |
| K. pneumoniae            | ATCC 700603      | $10^7$ | Synthetic fibers | RT | >8 w | [34] |
| P. mirabilis             | 2 isolates from a hospital | $10^2$–$10^5$ | Polyester | 22°C–26°C | 2 h to 2–4 d | [27] |
| P. aeruginosa            | 2 isolates from a hospital | $10^2$–$10^5$ | Polyester | 22°C–26°C | <1 h to 1–2 d | [27] |
| P. aeruginosa            | ATCC 27583       | $10^7$ | Synthetic fibers | RT | >8 w | [34] |
| S. marcescens            | 2 isolates from a hospital | $10^2$–$10^5$ | Polyester | 22°C–26°C | 1 h to 4–7 d | [27] |
| S. aureus                | ATCC 25923       | $10^5$–$10^6$ | Polyester | 27°C | 1–3 d | [45] |
| S. aureus                | 15 multi-resistant strains | $10^5$–$10^6$ | Polyester | 25°C | ≥7 d | [24] |
| S. aureus                | 6 isolates from a hospital (3 MRSA) | $10^7$ | Polyester | 23°C–24°C | 10–56 d | [33] |
| S. aureus                | NCTC 6538        | $10^8$ | Polyester | 23°C | <21 d | [36] |
| S. aureus                | NCTC 7447        | $10^5$–$10^6$ | Polyester | RT | 46–206 d* | [35] |
| S. aureus                | ATCC 25923       | $10^7$ | Synthetic fibers | RT | >8 w | [34] |
| Staphylococcus spp.      | 6 coagulase-negative isolates from a hospital (3 methicillin-resistant) | $10^7$ | Polyester | 23°C–24°C | 7–22 d | [33] |
| S. pyogenes              | DMU 724          | $10^5$–$10^6$ | Polyester | RT | 46–206 d* | [35] |

RT = room temperature; *longer survival at higher air humidity

(S. maltophilia). Short survival times were found with S. typhimurium (≥1 d), N. gonorrhoeae (up to 1 d), and S. dysenteriae (4 h). Low inocula of 100 CFU were often associated with shorter survival times, e.g., in K. pneumoniae (1–3 d), Acinetobacter spp. (7 h), E. coli (≤6 h) or P. mirabilis, P. aeruginosa and S. marcescens (≤1 h). Longer survival was associated with higher air humidity in K. pneumoniae, M. morganii, P. mirabilis, S. aureus and S. epidermidis (Table 3).

Fungi
Most fungal species applied as high inocula were able to survive at room temperature on various types of fibers for 30 d or more (A. fumigatus, C. glabrata, C. kruusei, C. parapsilosis, C. tropicalis, C. neoformans), 21 d (G. candidum), or 14 d (C. albicans). The differences between the fiber materials were variable. Four fungal species survived better on cotton or wool, three species on the blended fiber, and two on silk (Table 4).
Table 4: Survival of fungi on different types of fibers

| Species          | Strains/isolates | Inoculum          | Material                                         | Temperature | Survival | Reference |
|------------------|------------------|-------------------|--------------------------------------------------|-------------|----------|-----------|
| *A. fumigatus*   | Clinical isolate | $10^7$             | Silk                                             | 21°C–24°C   | 27 d     | [25]      |
| *A. fumigatus*   | Clinical isolate | $10^7$             | Cotton                                           | 21°C–24°C   | >30 d    | [25]      |
| *A. fumigatus*   | Clinical isolate | $10^7$             | Blend of 60% cotton and 40% polyester            | 21°C–24°C   | >30 d    | [25]      |
| *A. fumigatus*   | Clinical isolate | $10^7$             | Wool                                            | 21°C–24°C   | >30 d    | [25]      |
| *C. albicans*    | Clinical isolate | $10^7$             | Silk                                            | 21°C–24°C   | 6 d      | [25]      |
| *C. albicans*    | Clinical isolate | $10^7$             | Blend of 60% cotton and 40% polyester            | 21°C–24°C   | 6 d      | [25]      |
| *C. albicans*    | Clinical isolate | $10^7$             | Wool                                            | 21°C–24°C   | 12 d     | [25]      |
| *C. albicans*    | Clinical isolate | $10^7$             | Cotton                                           | 22°C        | 14 d     | [53]      |
| *C. albicans*    | Clinical isolate | $10^7$             | Blend of 50% cotton and 50% polyester            | 22°C        | 14 d     | [53]      |
| *C. glabrata*    | Clinical isolate | $10^7$             | Cotton                                           | 21°C–24°C   | >30 d    | [25]      |
| *C. glabrata*    | Clinical isolate | $10^7$             | Blend of 60% cotton and 40% polyester            | 21°C–24°C   | >30 d    | [25]      |
| *C. glabrata*    | Clinical isolate | $10^7$             | Wool                                            | 21°C–24°C   | >30 d    | [25]      |
| *C. glabrata*    | Clinical isolate | $10^7$             | Silk                                            | 21°C–24°C   | >30 d    | [25]      |
| *C. krusei*      | Clinical isolate | $10^7$             | Cotton                                           | 21°C–24°C   | 3 d      | [25]      |
| *C. krusei*      | Clinical isolate | $10^7$             | Blend of 60% cotton and 40% polyester            | 21°C–24°C   | 6 d      | [25]      |
| *C. krusei*      | Clinical isolate | $10^7$             | Silk                                            | 21°C–24°C   | 21 d     | [25]      |
| *C. krusei*      | Clinical isolate | $10^7$             | Wool                                            | 21°C–24°C   | >30 d    | [25]      |
| *C. parapsilosis*| Clinical isolate | $10^7$             | Cotton                                           | 22°C        | 14 d     | [53]      |
| *C. parapsilosis*| Clinical isolate | $10^7$             | Blend of 50% cotton and 50% polyester            | 22°C        | 14 d     | [53]      |
| *C. parapsilosis*| Clinical isolate | $10^7$             | Cotton                                           | 21°C–24°C   | >30 d    | [25]      |
| *C. parapsilosis*| Clinical isolate | $10^7$             | Blend of 60% cotton and 40% polyester            | 21°C–24°C   | >30 d    | [25]      |
| *C. parapsilosis*| Clinical isolate | $10^7$             | Wool                                            | 21°C–24°C   | >30 d    | [25]      |
| *C. parapsilosis*| Clinical isolate | $10^7$             | Silk                                            | 21°C–24°C   | >30 d    | [25]      |
| *C. tropicalis*  | Clinical isolate | $10^7$             | Cotton                                           | 21°C–24°C   | 3 d      | [25]      |
| *C. tropicalis*  | Clinical isolate | $10^7$             | Blend of 60% cotton and 40% polyester            | 21°C–24°C   | 6 d      | [25]      |
| *C. tropicalis*  | Clinical isolate | $10^7$             | Silk                                            | 21°C–24°C   | 24 d     | [25]      |
| *C. tropicalis*  | Clinical isolate | $10^7$             | Wool                                            | 21°C–24°C   | >30 d    | [25]      |
| *C. neoformans*  | Clinical isolate | $10^7$             | Cotton                                           | 21°C–24°C   | >30 d    | [25]      |
| *C. neoformans*  | Clinical isolate | $10^7$             | Blend of 60% cotton and 40% polyester            | 21°C–24°C   | >30 d    | [25]      |
| *C. neoformans*  | Clinical isolate | $10^7$             | Wool                                            | 21°C–24°C   | >30 d    | [25]      |
| *C. neoformans*  | Clinical isolate | $10^7$             | Silk                                            | 21°C–24°C   | >30 d    | [25]      |
| *G. candidum*    | Clinical isolate | $10^7$             | Blend of 60% cotton and 40% polyester            | 21°C–24°C   | 6 d      | [25]      |
| *G. candidum*    | Clinical isolate | $10^7$             | Silk                                            | 21°C–24°C   | 6 d      | [25]      |
| *G. candidum*    | Clinical isolate | $10^7$             | Wool                                            | 21°C–24°C   | 12 d     | [25]      |
| *G. candidum*    | Clinical isolate | $10^7$             | Cotton                                           | 21°C–24°C   | 21 d     | [25]      |

**Viruses**

**Cotton**

At room temperature, some viruses persisted for long periods of time, such as the variola virus (18 m), vaccinia virus (up to 2 w), rabbit haemorrhagic disease virus (up to 10 d) or poliovirus (up to 7 d). The majority of viruses lose their infectivity at room temperature on cotton within 1 d (coronavirus, cytomegalivirus, ebolavirus, influenza A virus, influenza B virus, metapneumovirus). Low inocula have a substantially shorter persistence, as
Table 5: Persistence of viruses on cotton

| Species                        | Strains/Isolates     | Inoculum   | Material       | Temperature | Persistence | Reference |
|--------------------------------|----------------------|------------|----------------|-------------|-------------|-----------|
| Coronavirus                    | Strains 229E and OC43| 5 × 10^3   | Cotton         | 21°C        | ≤ 8 h       | [54]      |
| Coronavirus                    | Clinical isolate of SARS coronavirus | 10^0 10^5 10^4 | Cotton gown     | RT          | 24 h 1 h 5 min | [55]      |
| Cytomegalievirus               | Clinical isolate from urine | Unknown    | Cotton         | 25°–27°C   | ≤ 2 h       | [56]      |
| Cytomegalievirus               | Strain AD169         | 200        | Cotton         | RT          | ≤ 8 h       | [57]      |
| Ebolavirus                     | Clinical isolate     | 10^7       | Cotton gown     | 21.5°C      | < 24 h      | [58]      |
| Influenza A Virus              | Strain NIBRG-1215w (H1N1) | 10^5       | Cotton pillowcases | RT          | 8 h         | [59]      |
| Influenza-A-Virus              | Strain 1178 (H1N1)   | 10^3       | Cotton pillowcases | 28°C        | 12 h        | [60]      |
| Influenza A Virus              | Strain Delaware 47186 (H13N7) | 6x10^4   | Cotton handkerchief | RT          | 1 d         | [61]      |
| Influenza-B-Virus              | Strain 1/79          | 10^3       | Cotton handkerchief | 28°C        | 10 h        | [60]      |
| Metapneumovirus                | Strain APV/MN-2a     | 3x10^6     | Cotton         | RT          | 1 d         | [61]      |
| Poliovirus                     | Type 2               | 10^3–10^10 | Cotton (sheeting, terry cloth, knit jersey) | 25°C    | 4–7 d       | [62]      |
| Poliovirus                     | Type 1               | Unknown    | Cotton         | 18°–20°C   | 143 h*      | [63]      |
| Rabbit haemorrhagic disease virus | Strain CAPM V-351 | 10^6–10^7 | Cotton         | 15°C        | 10 d        | [64]      |
| Reovirus                       | Strain R2, strain S1133 | 10^3–10^4 | Cotton         | 23°–26°C   | 1–4 d       | [65]      |
| Vaccinia virus                 | Strain Lederle       | 10^3–10^5 | Cotton (sheeting, terry cloth, knit jersey) | 25°C    | 1–2 w       | [66]      |
| Variola virus                  | Clinical isolate     | 5x10^5     | Cotton         | 4°C 20°–24°C | ≥10 y 18 m 60–70 d | [67]      |

RT = room temperature; *2 log_{10} reduction

demonstrated with the coronavirus. The variola virus remained infectious for more than 10 years at 4°C (Table 5).

### Synthetic fibers

On synthetic fibers, some viruses kept their infectivity at room temperature for 12 d (ebolavirus), up to 7 d (influenza A virus, norovirus), or up to 3 d (calicivirus). The metapneumovirus could only persist for less than 1 d (Table 6).

### Mixed and other fibers

On the different types of fibers, viruses kept their infectivity at room temperature for up to 28 d (vaccinia virus), 14 d (calicivirus, norovirus), 12 d (foot-and-mouth disease virus) and 10 d (poliovirus). The influenza A virus, however, persisted only for up to 1 h. A low temperature enabled the vaccinia virus to persist longer, whereas the foot-and-mouth disease virus lost its infectivity sooner (Table 7).

### Discussion

The compilation of data shows that the survival of bacteria at room temperature was the longest on polyester (up to 206 d), whereas it was 90 d for some species on cotton and mixed fibers. Only low inocula of 100 CFU were found on all types of textiles with a short survival time of ≤3 d. Most bacterial species survived better at elevated air humidity. The infectivity of viruses on textiles is lost much faster at room temperature, typically within 2–4 w. These data show that contaminated textiles may well serve as a source of transmission, provided the inoculum is high enough. Elevated air humidity is an advantage for survival of bacteria. These data may have implications for the washing intervals of clothes worn at work. The duration of wear has an
impact on the overall microbial load. It has been shown that the bacterial contamination of nurses’ coats is significantly higher after the second shift than after the first [9]. The change intervals in clinical practice may not reflect the real risk of contaminated clothes. In France, doctors changed their coats on average every 20 days [10]. Contaminated clothes may also have an impact on the contamination of the HCWs’ hands and vice versa. The presence of pathogens on coats is associated with the presence of pathogens on the hands of HCWs, whence they were probably originally transferred to the coats. Nevertheless, this still suggests that a contaminated coat can serve as a reservoir for contamination of the HCWs’ hands [11]. It has therefore been proposed that doctors leave their arms bare below the elbows, hang up their coat before patient contact, and launder their coat daily [12].

The impregnation of textiles with antimicrobial agents such as silver compounds, triclosan or copper has also been discussed to reduce their contamination in healthcare [13]. Copper-impregnated textiles can reduce multi-resistant bacterial species within 1 h [14]. Among chronic ventilator-dependent patients, a significant reduction of healthcare infections indicators, such as antibiotic treatment initiation events, fever days and antibiotic usage, was described when the HCWs wore copper-oxide impregnated textiles instead of regular hospital textiles [15]. Copper-impregnated linens were even described to

Table 6: Persistence of viruses on synthetic fibers

| Species          | Strains/isolates               | Inoculum | Material          | Temperature | Persistence | Reference |
|------------------|--------------------------------|----------|-------------------|-------------|-------------|-----------|
| Calicivirus      | Feline calicivirus strain F9   | 10⁶      | Nylon carpet fibers | RT          | 1–3 d       | [68]      |
| Ebolavirus       | Clinical isolate              | 10⁷      | Tyvek             | 21°C/27°C   | 12 d/3 d    | [69]      |
| Influenza A Virus| Strain Delaware 471/86 (H1N7) | 6x10⁴    | Polyester         | RT          | <1 d       | [61]      |
| Influenza A Virus| 5 strains (H1N1)              | Unknown  | Microfibre        | RT          | 1 w        | [70]      |
| Metapneumovirus  | Strain APV/MN-2a              | 3x10⁴    | Polyester         | RT          | <1 d       | [61]      |
| Norovirus        | Murine norovirus strain CW3   | 10⁶      | Nylon carpet fibers | RT          | 7 d        | [68]      |

RT=room temperature

Table 7: Persistence of viruses on mixed and other fibers

| Species                  | Strains/isolates               | Inoculum | Material          | Temperature | Persistence | Reference |
|--------------------------|--------------------------------|----------|-------------------|-------------|-------------|-----------|
| Calicivirus              | Feline calicivirus strain F9   | 10⁵      | Wool              | RT          | 7–14 d      | [68]      |
| Influenza A Virus        | Clinical isolate (H1N1)        | 30       | Facial tissue     | RT          | <15 min <15 min ≤15 min | [71] |
| Influenza A Virus        | Clinical isolate (H1N1)        | 30       | Pillow case       | RT          | <15 min ≤15 min ≤60 min | [71] |
| Foot-and-mouth disease virus | 3 strains           | Unknown  | Wool              | 4°C/18°C/37°C | 2–3 d/11–12 d/33–68 h | [72] |
| Norovirus                | Murine norovirus strain CW3    | 10⁶      | Wool              | RT          | 7–14 d      | [68]      |
| Parainfluenzavirus       | 3 strains                     | 10⁴      | Lab coat          | 22°C        | 0–4 h*      | [73]      |
| Parainfluenzavirus       | 3 strains                     | 10⁴      | Facial tissue     | 22°C/2°C    | 2 h         | [73]      |
| Poliovirus               | Type 2                        | 10⁶–10¹⁰ | Wool (blanket, gabanine) | 25°C        | 10 d        | [62]      |
| Respiratory syncytial virus | Clinical isolate              | 10⁵      | Paper facial tissue | 22°C–25°C   | 1 h         | [74]      |
| Respiratory syncytial virus | Clinical isolate              | 10⁵      | Cloth gowns (cotton and polyester) | 22°C–25°C | 1–2 h | [74] |
| Vaccinia virus           | Strain VR119                   | 10⁷      | Carpet            | 21°C–23°C/6°C–7°C | <1–14 d**/ 21–66 d** | [75] |
| Vaccinia virus           | Strain Lederle                 | 10⁶–10⁹  | Wool (blanket, gabanine) | 25°C        | 2–4 w       | [66]      |

RT=room temperature; *depending on the type of coat; **longer persistence at lower air humidity
reduce healthcare-associated *C. difficile* infections [16]. Despite all the encouraging results, the permanent exposure of nosocomial pathogens to a biocidal agent is likely to enhance tolerance to this agent [17]. *A. baumannii*, for example, has been described to become resistant to copper, also by exposure to subinhibitory concentrations of copper [18]. The increased tolerance may well be explained by copper efflux systems [19]. Certain *P. aeruginosa* isolates have also been found to possess copper tolerance [20]. Items with permanent biocidal impregnation should therefore be regarded with great caution, because it seems to be a matter of time before nosocomial pathogens develop a tolerance to them, possibly even a cross-tolerance to other biocidal agents or antibiotics [21], [22], [23].

**Conclusions**

Contaminated textiles or fabrics may be a source of transmission for weeks. The presence of pathogens on the coats of healthcare workers is associated with the presence of pathogens on their hands, demonstrating the relevance of textile contamination in patient care.

**Notes**

Competing interests

The author declares that he has no competing interests.

**References**

1. Mahida N, Prescott K, Yates C, Spencer F, Weston V, Boswell T. Outbreak of invasive group A streptococcus: investigations using agar settle plates detect perineal shedding from a healthcare worker. *J Hosp Infect.* 2018;100(4):e209-e215. DOI: 10.1016/j.jhin.2018.03.029

2. Das I, Lambert P, Hill D, Noy M, Bion J, Elliott T. Carbapenem-resistant Acinetobacter and role of curtains in intensive care units. *J Hosp Infect.* 2002 Feb;50(2):110-4. DOI: 10.1053/jh.2001.1127

3. Weernink A, Severin WP, Tjernberg I, Djikshoorn L, Pillows, an unexpected source of Acinetobacter. *J Hosp Infect.* 1995;29(3):189-99.

4. Cheng VCC, Chen JHK, Leung SSM, So SYC, Wong SC, Wong SCY, Tse H, Yuen KY. Seasonal Outbreak of Bacillus Bacteremia Associated With Contaminated Linen in Hong Kong. *Clin Infect Dis.* 2017 May;64(suppl_2):S91-S97. DOI: 10.1093/cid/csx044

5. Hosein IK, Hoffman PN, Elsam S, Asseem TM, Fakokunde A, Silles J, Devereux E, Kaur D, Bosanquet J. Summertime Bacillus cereus colonization of hospital newborns traced to contaminated, laundered linen. *J Hosp Infect.* 2013 Oct;85(2):149-54. DOI: 10.1016/j.jhin.2013.06.001

6. John AR, Ahmadi H, Gonzalez-Orta MI, Cadnum JL, Donskey CJ. A Randomized Trial to Determine Whether Wearing Short-Sleeved White Coats Reduces the Risk for Pathogen Transmission. *Infect Control Hosp Epidemiol.* 2018 02;39(2):233-234. DOI: 10.1017/ice.2017.264

7. Arrow PM, Houchins SG, Pugliese G. An outbreak of tinea corporis in hospital personnel caused by a patient with Trichophyton tonsurans infection. *Pediatr Infect Dis J.* 1991 May;10(5):355-9. DOI: 10.1097/00006454-199105000-00002

8. Kramer A, Schwiebke I, Kampf G. How long do nosocomial pathogens persist on inanimate surfaces? A systematic review. *BMC Infect Dis.* 2006 Aug;6:130. DOI: 10.1186/1471-2334-6-130

9. Gupta P, Bairagi N, Priyadarshini R, Singh A, Chauhan D, Gupta D. Bacterial contamination of nurses‘ white coats after first and second shift. *Am J Infect Control.* 2017 01;45(1):86-88. DOI: 10.1016/j.ajic.2016.07.014

10. Gouraud D, Dumont R, Asehounou K, Lejus C. White coats: how long should doctors wear them? *Ann Fr Anesth Reanim.* 2014 Jan;33(1):e23-5. DOI: 10.1016/j.anfar.2013.11.012

11. Munoz-Price LS, Arheart KL, Mills JP, Cleary T, Depascale D, Jimenez A, Fajardo-Aquino Y, Coro G, Birnbach DJ, Lubansky DA. Associations between bacterial contamination of health care workers‘ hands and contamination of white coats and scrubs. *Am J Infect Control.* 2012 Nov;40(9):e245-8. DOI: 10.1016/j.jhin.2012.02.032

12. Kuehn BM. Time to hang up the white coat? Epidemiologists suggest ways to prevent clothing from spreading infection. *JAMA.* 2014 Feb;311(8):786-7. DOI: 10.1001/jama.2014.794

13. Kramer A, Guggenbichler P, Heldt P, Jünger M, Ladwig A, Thierbach H, Weber U, Daeschlein G. Hygienic relevance and risk assessment of antimicrobial-impregnated textiles. *Curr Probl Dermatol.* 2006;33:78-109. DOI: 10.1159/000093938

14. Irene G, Georgios P, Ioannis C, Anastasios T, Diamantis P, Marianieth C, Philippe W, Maria S. Copper-coated textiles: armor against MDR nosocomial pathogens. *Diagn Microbiol Infect Dis.* 2016 Jun;85(2):205-9. DOI: 10.1016/j.diagmicrobio.2016.02.015

15. Marcus EL, Yosef H, Borkow G, Caine Y, Sasson A, Moses AE. Reduction of healthcare-associated infection indicators by copper oxide-impregnated textiles: Crossover, double-blind controlled study in chronic ventilator-dependent patients. *Am J Infect Control.* 2017 Apr;45(4):401-403. DOI: 10.1016/j.jhin.2016.11.022

16. Butler JP. Effect of copper-impregnated composite bed linens on patient gowns and healthcare-associated infection rates in six hospitals. *J Hosp Infect.* 2018 Nov;100(3):e130-e134. DOI: 10.1016/j.jhin.2018.05.013

17. Kampf G. Antiseptic Stewardship: Biocide Resistance and Clinical Implications. Cham: Springer International Publishing; 2018. DOI: 10.1007/978-3-319-98785-9

18. Williams CL, Neu HM, Gilbreath JJ, Michel SL, Zurawski DV, Merrell DS. Copper Resistance of the Emerging Pathogen Acinetobacter baumannii. *Appl Environ Microbiol.* 2016 10;82(20):6174-6188. DOI: 10.1128/AEM.01813-16

19. Alquethamy SF, Khorvash M, Pederick VG, Whittall JJ, Paton JC, Williams CL, Neu HM, Gilbreath JJ, Michel SL, Zurawski DV, Paulsen IT, Hassan KA, McDevitt CA, Eijkelkamp BA. The Role of *Acinetobacter baumannii* in hospital plumbing system by persister cells and their antibiotic resistance in Gram-Negative Species. *Antibiotics (Basel).* 2018 Dec;7(4):10.3390/antibiotics7040110
Kampf: How long can nosocomial pathogens survive on textiles? ...

23. Kampf G. Antibiotic Resistance Can Be Enhanced in Gram-Positive Species by Some Bacterial Agents Used for Disinfection. Antibiotics (Basel). 2019 Feb;8(1). DOI: 10.3390/antibiotics8010013

24. Hanczviikkel A, Tóth Á. Quantitative study about the role of environmental conditions in the survival capability of multidrug-resistant bacteria. J Infect Public Health. 2018 Nov-Dec;11(6):801-806. DOI: 10.1016/j.jiph.2018.05.001

25. Koca O, Altoparlak U, Ayyildiz A, Kaynar H. Persistence of nosocomial pathogens on various fabrics. Eurasian J Med. 2012 Apr;44(1):28-31. DOI: 10.5152/eajm.2012.06

26. Hirai Y. Survival of bacteria under dry conditions; from a viewpoint to the nonsexual transmission of gonococcal infection. J Hosp Infect. 1991 Nov;19(3):191-200. DOI: 10.1016/0195-6701(91)90223-u

27. Neely AN. A survey of gram-negative bacteria survival on hospital fabrics and plastics. J Burn Care Rehabil. 2000 Nov-Dec;21(6):523-7. DOI: 10.1097/00004630-200021060-00009

28. Yrios JW, Balish E, Helstad A, Field C, Inhorn S. Survival of anaerobic and aerobic bacteria on cotton swabs in three transport systems. J Clin Microbiol. 1975 Feb;1(2):196-200.

29. Drabick JA, Gracely EJ, Heidecker GJ, LiPuma JJ. Survival of Escherichia coli and Staphylococcus aureus on textiles used in healthcare uniforms. J Appl Microbiol. 2017 Jul;123(1):280-286. DOI: 10.1111/j.1365-2672.2005.02620.x

30. De Cesare A, Sheldon BW, Smith KS, Jaykus LA. Survival and fluid contamination on different hospital surfaces and devices. J Hosp Infect. 1996 Apr;32(4):267-76. DOI: 10.1016/s0195-6701(96)90037-7

31. Rubbo SD, Benjamin M. Some observations on survival of pathogenic bacteria on cotton-wool swabs; development of a new type of swab. Br Med J. 1951 May;1(4713):983-7. DOI: 10.1136/bmj.1.4713.983

32. Ross PW, Lough H. Survival of upper respiratory tract bacteria on cotton-wool swabs. J Clin Pathol. 1978 May;31(5):430-3. DOI: 10.1136/jcp.31.5.430

33. Neely AN, Maley MP. Survival of enterococci and staphylococci on hospital fabrics and plastic. J Clin Microbiol. 2000 Feb;38(2):724-6.

34. Esteves DC, Pereira VC, Souza JM, Davies A, Laird K. The effect of low-temperature laundering and detergents on the survival of Escherichia coli and Staphylococcus aureus on textiles used in healthcare uniforms. J Appl Microbiol. 2017 Jul;123(1):280-286. DOI: 10.1111/j.1365-2672.2005.02620.x

35. Jenkins RO, Sherburn RE. Growth and survival of bacteria on cotton-wool swabs in three transport systems. J Clin Microbiol. 1975 Feb;1(2):196-200.

36. Riley K, Williams J, Owen L, Shenn J, Davies A, Laird K. The effect of low-temperature laundering and detergents on the survival of Escherichia coli and Staphylococcus aureus on textiles used in healthcare uniforms. J Appl Microbiol. 2017 Jul;123(1):280-286. DOI: 10.1111/j.1365-2672.2005.02620.x

37. Elmors T. Survival of Neisseria gonorrhoeae on surfaces. Acta Derm Venereol. 1977;57(2):177-80. DOI: 10.2340/00015555-71780

38. Srivastava AC. Survival of gonococci in urethral secretions with secretion to the nonsexual transmission of gonococcal infection. J Med Microbiol. 1980 Nov;13(4):593-6. DOI: 10.1099/00222615-13-4-593

39. Spicer CC. The survival of Shigella sonnei on cotton threads. J Hyg (Lond). 1959 Jun;57(2):210-5. DOI: 10.1017/s0022274000020052

40. Nakamura M. The survival of Shigella sonnei on cotton, glass, wood, paper, and metal at various temperatures. J Hyg (Lond). 1962 Mar;60:35-9. DOI: 10.1017/s0022274000029280

41. Zarpellon MN, Gales AC, Sasaki AL, Selhorst GJ, Menegucci TC, Cardoso CL, Garcia LB, Tognim MC. Survival of vancomycin-intermediate Staphylococcus aureus on hospital surfaces. J Hosp Infect. 2015 Aug;90(4):347-50. DOI: 10.1016/j.jhin.2015.04.005

42. Desai R, Pannaraj PS, Agopian J, Sugar CA, Liu GY, Miller LG. Survival and transmission of community-associated methicillin-resistant Staphylococcus aureus from fomites. Am J Infect Control. 2011 Apr;39(3):219-25. DOI: 10.1016/j.ajic.2010.07.005

43. Durham AE, Hall YS, Kulp L, Underwood C. A study of the environmental survival of Streptococcus equi subspecies equi. Equine Vet J. 2018 Nov;50(6):861-864. DOI: 10.1111/eve.12840

44. Farhana I, Hossain ZZ, Tulsiani SM, Jensen PK, Begum A. Survival of Vibrio cholerae O1 on fomites. World J Microbiol Biotechnol. 2016 Sep;32(9):146. DOI: 10.1007/s11274-016-2100-x

45. Cuesta A, Nastri N, Bernat M, Brusca M, Turcot L, Nastri M, Rosa AC. Survival of Staphylococcus aureus on fomites. Acta Odontol Latinoam. 2008;21(2):141-6.

46. López-Gigoso R, Mariscal A, Gutiérrez-Bedmar M, Mariscal López E, Fernández-Grihuet J. Persistence of nosocomial bacteria on 2 biocidal fabrics based on silver under conditions of high relative humidity. Am J Infect Control. 2014 Aug;42(8):879-84. DOI: 10.1016/j.ajic.2014.04.019

47. Weber DJ, Rutala WA, Kanamori H, Gergen MF, Sickbert-Bennett EE. Carbapenem-resistant Enterobacteriaceae: frequency of hospital room contamination and survival on various inoculated surfaces. Infect Control Hosp Epidemiol. 2015 May;36(5):590-3. DOI: 10.1017/ice.2015.17

48. Lanikford MG, Collins S, Youngberg L, Rooney DM, Warren JR, Noskin GA. Assessment of materials commonly utilized in healthcare care: implications for bacterial survival and transmission. Am J Infect Control. 2006 Jun;34(4):258-63. DOI: 10.1016/j.ajic.2005.10.008

49. Pérez JL, Gómez E, Sauca G. Survival of gonococci from urethral discharge on fomites. Eur J Clin Microbiol Infect Dis. 1990 Jan;9(1):54-5. DOI: 10.1007/bf01969538

50. Islam MS, Hossain MA, Khan SI, Khan MN, Sack RB, Albert MJ, Huq A, Colwell RR. Survival of Shigella dysenteriae type 1 on fomites. J Health Popul Nutr. 2001 Sep;19(3):177-82.

51. Dawson P, Han I, Cox M, Black C, Simmons L. Residence time and food contact time effects on transfer of Salmonella Typhimurium from tile, wood and carpet: testing the five-second rule. J Appl Microbiol. 2007 Apr;102(4):945-53. DOI: 10.1111/j.1365-2672.2006.03171.x

52. Huang R, Mehta S, Weed D, Price CS. Methicillin-resistant Staphylococcus aureus survival on hospital fomites. Infect Control Hosp Epidemiol. 2006 Nov;27(11):1267-9. DOI: 10.1086/507065

53. Traoré O, Springthorpe VS, Sattar SA. Quantitative study of the survival of two species of Candida on porous and non-porous environmental surfaces and hands. J Appl Microbiol. 2002;92(3):549-55. DOI: 10.1046/j.1365-2672.2002.01560.x

54. Sizun J, Yu MW, Talbot PJ. Survival of human coronaviruses 229E and OC43 in suspension and after drying on surfaces: a possible source of hospital-acquired infections. J Hosp Infect. 2000 Sep;46(1):55-60. DOI: 10.1016/j.ajic.2010.07.005

55. Lai MY, Cheng PK, Lim WW. Survival of severe acute respiratory syndrome coronavirus. Clin Infect Dis. 2005 Oct;41(7):e67-71. DOI: 10.1086/433186
56. Faix RG. Survival of cytomegalovirus on environmental surfaces. J Pediatr. 1985 Apr;106(4):649-52. DOI: 10.1016/s0022-3476(85)80096-2

57. Stowell JD, Forlin-Passoni D, Din E, Radford K, Brown D, White A, Bate SL, Dollard SC, Bialek SR, Cannon MJ, Schmid DS. Cytomegalovirus survival on common environmental surfaces: opportunities for viral transmission. J Infect Dis. 2012 Jan;205(2):211-4. DOI: 10.1093/infdis/jir722

58. Cook BW, Cutts TA, Nikiforuk AM, Poliquin PG, Court DA, Strong JE, Theriault SS. Evaluating environmental persistence and disinfection of the Ebola virus Makona variant. Viruses. 2015 Apr;7(4):1975-86. DOI: 10.3390/v7041975

59. Oxford J, Berezin EN, Courvalin P, Dwyer DE, Exner M, Jana LA, Kaku M, Lee C, Letelipe K, Low DE, Madani TA, Rubino JR, Saini N, Schoub BD, Signorelli C, Tiero PM, Zhong X. The survival of influenza A(H1N1)pdm09 virus on 4 household surfaces. Am J Infect Control. 2014 Apr;42(4):423-5. DOI: 10.1016/j.jinf.2013.10.016

60. Bean B, Moore BM, Sterner B, Peterson LR, Gerding DN, Balfour HH Jr. Survival of influenza viruses on environmental surfaces. J Infect Dis. 1982 Jul;146(1):47-51. DOI: 10.1093/infdis/146.1.47

61. Tiwari A, Patnayak DP, Chander Y, Parsad M, Goyal SM. Survival of two avian respiratory viruses on porous and nonporous surfaces. Avian Dis. 2006 Jun;50(2):284-7. DOI: 10.1637/7453-101205R.1

62. Dixon GJ, Sidwell RW, McNeil E. Quantitative studies on fabrics as disseminators of viruses. II. Persistence of poliomyelitis virus on cotton and wool fabrics. Appl Microbiol. 1966 Mar;14(2):183-8.

63. Tamrakar SB, Henley J, Gurian PL, Gerba CP, Mitchell J, Enger K, Rose JB. Persistence analysis of poliovirus on three different types of fomites. J Appl Microbiol. 2017 Feb;122(2):522-530. DOI: 10.1111/jam.13299

64. Henning J, Meers J, Davies PR, Morris RS. Survival of rabbit haemorrhagic disease virus (RHDV) in the environment. Epidemiol Infect. 2005 Aug;133(4):719-30. DOI: 10.1017/s0950268805003766

65. Savage CE, Jones RC. The survival of avian reoviruses on materials associated with the poultry house environment. Avian Pathol. 2003 Aug;32(4):419-26.

66. Sidwell RW, Dixon GJ, McNeil E. Quantitative studies on fabrics as disseminators of viruses. I. Persistence of vaccinia virus on cotton and wool fabrics. Appl Microbiol. 1966 Jan;14(1):55-9.

67. MacCallum FO, McDonald JR. Survival of variola virus in raw cotton. Bull World Health Organ. 1957;16(2):247-54.

68. Buckley D, Fraser A, Huang G, Jiang X. Recovery Optimization and Survival of the Human Norovirus Surrogates Feline Calicivirus and Murine Norovirus on Carpet. Appl Environ Microbiol. 2017 Nov;83(22). DOI: 10.1128/AEM.01336-17

69. Fischer R, Judson S, Miazgowicz K, Bushmaker T, Prescott J, Munster VJ. Ebola Virus Stability on Surfaces and in Fluids in Simulated Outbreak Environments. Emerging Infect Dis. 2015 Jul;21(7):1243-6. DOI: 10.3201/eid2107.150253

70. Thompson KA, Bennett AM. Persistence of influenza on surfaces. J Hosp Infect. 2017 Feb;95(2):194-199. DOI: 10.1016/j.jhin.2016.12.003

71. Mukherjee DV, Cohen B, Bovino ME, Desai S, Whittier S, Larson EL. Survival of influenza virus on hands and fomites in community and laboratory settings. Am J Infect Control. 2012 Sep;40(7):590-4. DOI: 10.1016/j.ajic.2011.09.006

72. McColl KA, Westbury HA, Kitching RP, Lewis VM. The persistence of foot-and-mouth disease virus on wool. Aust Vet J. 1995 Aug;72(8):286-92. DOI: 10.1111/j.1751-0813.1995.tb03556.x

73. Brady MT, Evans J, Cuartas J. Survival and disinfection of parainfluenza viruses on environmental surfaces. Am J Infect Control. 1990 Feb;18(1):18-23. DOI: 10.1016/0196-6553(90)90206-8

74. Hall CB, Douglas RG Jr, Geiman JM. Possible transmission by fomites of respiratory syncytial virus. J Infect Dis. 1980 Jan;141(1):98-102. DOI: 10.1093/infdis/141.1.98

75. Wood JP, Choi YW, Wendling MQ, Rogers JV, Chappie DJ. Environmental persistence of vaccinia virus on materials. Lett Appl Microbiol. 2013 Nov;57(5):399-404. DOI: 10.1111/lam.12126

Corresponding author:
Prof. Dr. Günter Kampf
University Medicine Greifswald, Institute for Hygiene and Environmental Medicine, Ferdinand-Sauerbruch-Straße, 17475 Greifswald, Germany
guenther.kampf@uni-greifswald.de

Please cite as
Kampf G. How long can nosocomial pathogens survive on textiles? A systematic review. GMS Hyg Infect Control. 2020;15:Doc10. DOI: 10.3205/dgkh000345, URN: urn:nbn:de:0183-dgkh0003451

This article is freely available from https://www.egms.de/en/journals/dgkh/2020-15/dgkh000345.shtml

Published: 2020-05-15

Copyright
©2020 Kampf. This is an Open Access article distributed under the terms of the Creative Commons Attribution 4.0 License. See license information at http://creativecommons.org/licenses/by/4.0/.