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Re-purposing of domestic steam disinfector within the hospital-at-home setting

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Received 21 August 2020; received in revised form 14 September 2020; accepted 15 September 2020
Available online 15 October 2020

KEYWORDS
Steam disinfection; Steam disinfector; Babies dummies; Pacifier; Thermal lethality; Hospital-at-home

Abstract  Background: Vulnerable patients being cared for in hospital-at-home settings require safe disinfection of their medical devices, including nebulisers and other respiratory equipment. The scale of patients now being cared for in hospital-at-home settings as a result of COVID19 places huge pressure on hospital central sterile services departments (CSSDs) to provide consumable items to safely support such patients’ care. This places new importance on the disinfection of mundane objects, including crockery, cutlery and frequently touched objects in the home environment. This study examined temperature performance of steam disinfectors and the consequences of potential operator misuse on the survival of 62 bacteria and yeast organisms.

Methods: Thermal performance of steam disinfectors was evaluated using calibrated thermocouple probes in multiple permutations of device usage with 62 test organisms.

Results: Thermocouple data demonstrated disinfection A0 values of 6000 (upper layer) and 60 (lower layer). Steam disinfection of baby bottles had a thermal lethality of at least A0 = 600. Variation in disinfector temperatures were noted, depending on the geometric location of thermocouples. Additional notable temperature reductions occurred with device underfilling with suboptimal water volumes. Steam disinfection eradicated all 62 non-spore-forming Gram-positive, Gram-negative and yeast organisms tested and eradicated all organisms in the inner teat space of contaminated babies’ dummies, rendering safe steam disinfection of babies’ dummies.

Conclusion: Domestic steam disinfection offers an inexpensive, simple, versatile and widely available technology for the elimination of common non-spore-forming nosocomial pathogens and safe disinfection of medical devices, fomites and other mundane objects within the hospital-at-home scenario, thereby enhancing patient safety.
Introduction

Hospital-at-home was first described in 1961 in Paris and in Bayonne in the Pyrenees France and was named “hospitalisation à domicile” [1]. Its primary objectives were to allow terminally-ill cancer patients to die at home, as well as caring for the elderly and chronic sick patients at home, employing, peripatetic nurses, nursing aides and physiotherapists. Such services allowed patients to remain in their own home environments, whilst relieving pressure from acute hospital services.

Hospital-at-home is defined by Cochrane Review as “a service that provides active treatment, by health care professionals, in the patient’s home of a condition that otherwise would require acute hospital in-patient care, always for a limited time period” [2]. These structures are healthcare institutions in their own right and hence require formal governance arrangements relating to both risk assessment, risk management and quality standards [3]. Their setting in the community coupled with remote management places major intrinsic constraints in operating such services. Nevertheless, the hospital-at-home healthcare model has now been adopted by several countries, including the US, Canada and the Netherlands, whilst in the UK, the approach has been to provide personal, nurse-led care [2]. To date, there have been few reports discussing infection control and prevention procedures relating to the hospital-at-home healthcare model.

Recently, the emergence of SARS CoV-2 virus in Asia relating to COVID-19 disease has placed unprecedented strain on healthcare systems worldwide, resulting in the discharge of patients from acute hospital care into the community delivered through hospital-at-home structures, in order to make provision for acute beds for COVID-19 patients. Such discharge into the community introduces new infection risks for vulnerable patient groups, including those with haematological malignancies, those with impaired immune systems and those with cystic fibrosis, both from traditional microbial pathogens associated with these patients, as well as new risks from SARS CoV-2. Recently published data [4,5] has demonstrated the thermal susceptibility of the coronaviruses to heat. Kampf and colleagues [4] examined thermal susceptibility data from 10 original studies and concluded that thermal disinfection at 60 °C for 30 min, 65 °C for 15 min and 80 °C for 1 min was effective to reduce coronavirus infectivity by at least 4 log10 units.

The scale and volume of patients now being cared for in hospital-at-home settings places huge pressure on hospital central sterile services departments (CSSDs) to provide consumable items to support such patients’ care. This is particularly true with the ongoing COVID19 pandemic, as many hospitals are discharging patients back to the community, to free-up beds for potential COVID19 patients, as well as to protect COVID-free patients from nosocomial transmission, associated with the uncertainty of virus transmission and epidemiology. Furthermore, in addition to the requirement to disinfect patients’ medical devices, specific infection control advice to extremely vulnerable patients regarding COVID-19, places new requirements for the disinfection of mundane objects, including crockery, cutlery and frequently touched objects in the home environment [6]. All of these scenarios have raised patient anxiety and have created an unprecedented need for effective disinfection procedures within the home to maintain patient safety.

The aim of this study was therefore to examine the re-purposing of domestic steam disinfectors to support home-based disinfection of medical devices, fomites and other mundane objects for vulnerable patient groups, by examining thermal performance and reconciling such performance with thermal inactivation of clinically important Gram-positive, Gram-negative and yeast organisms. A further important objective was to examine how patient misoperation of the device altered temperature profiling with subsequent consequences for pathogen survival.

Methods

Table 1 describes the bacteria (n = 7; Gram positive = 3; Gram negative = 4) and yeasts (n = 2) examined in this study. These bacteria included two hospital-associated MRSA (HA-MRSA), two community-associated MRSA (CA-MRSA) and one livestock-associated MRSA (LA-MRSA), as well as foodborne pathogens and other common nosocomial pathogens. Bacterial and yeast isolates were sub-cultured on Columbia Blood Agar (CBA; Oxoid CM0031, Oxoid Ltd., Basingstoke, UK), supplemented with 5% (v/v) defibrinated horse blood (Oxoid SR0050) and incubated aerobically for 24 h at 37 °C.
Microbial thermal inactivation studies

Individual inocula of each organism was freshly prepared by adding 17h culture into Maximum Recovery Diluent (Oxoid CM0733) to approximately a McFarland 0.5 standard. All inocula were enumerated quantitatively in duplicate, by employing the spiral plating technique, on Standard Plate Count Agar (SPC) (Oxoid CM0463), as previously described [7]. Using a PCR thermal cycler (GeneAmp® PCR System 9700; PerkinElmer Inc., USA) inocula solution (50 μl) were heated for 4 min at 51 °C, 59 °C, 67 °C, 75 °C, 83 °C and 91 °C, followed by 37 °C for 2 min. Exact temperatures of the thermal cycler wells were measured accurately against a thermal reference standard, as described below. When heating was completed, an inoculum (1 μl) was plated onto CBA and incubated, as described above for 24h and 48h. Additionally, in order to recover/enrich any remaining cells, the remaining heated inocula (49 μl) were transferred to nutrient broth (Oxoid CM1) (10 ml) and incubated for 48 h at 37 °C. Broths were checked for microbial growth at 24h and 48h heat, as determined by the development of cloudiness. All broths irrespective of cloudiness were streaked after 24h onto CBA and incubated as above for

| Table 1 Description of organisms employed in this study and their thermal susceptibility at six temperatures. |
|---------------------------------------------------------------|
| Isolate | Source | Inoculum used in thermal studies | Survival for 4 min at | Inoculum used in steam disinfection studies | Survival post steam disinfection |
|---------|--------|----------------------------------|----------------------|-----------------------------------------------|---------------------------------|
|         |        | (cfu)   | 51 °C | 59 °C | 67 °C | 75 °C | 83 °C | 91 °C | (cfu) |
| Gram positive |        |         |       |       |       |       |       |       |       |
| Enterococcus faecalis | WDCM 00009a | 1.15 × 10⁷ | +    | +    | +    | −    | −    | −    | 2.30 × 10⁷ | −    |
| Listeria monocytogenes | WDCM 00021a | 5.60 × 10⁷ | +    | +    | +    | −    | −    | −    | 1.12 × 10⁸ | −    |
| Staphylococcus aureus | Blood | 7.10 × 10⁶ | +    | +    | +    | −    | −    | −    | 1.42 × 10⁷ | −    |
| Staphylococcus aureus (HA-MRSA) | Blood | 1.01 × 10⁷ | +    | +    | +    | −    | −    | −    | 2.01 × 10⁷ | −    |
| Staphylococcus aureus (HA-MRSA) | Blood | 9.30 × 10⁶ | +    | +    | +    | −    | −    | −    | 1.86 × 10⁷ | −    |
| Staphylococcus aureus (LA-MRSA cc30) | Porcine | 1.39 × 10⁷ | +    | +    | +    | −    | −    | −    | 2.77 × 10⁷ | −    |
| Staphylococcus aureus (CA-MRSA ST35) | Clinical | 1.14 × 10⁷ | +    | +    | +    | −    | −    | −    | 2.28 × 10⁷ | −    |
| Staphylococcus aureus (CA-MRSA 4266) | Clinical | 8.35 × 10⁶ | +    | +    | +    | −    | −    | −    | 1.67 × 10⁷ | −    |
| Gram negative |        |         |       |       |       |       |       |       |       |
| Escherichia coli O157 eH7 | WDCM 00014a | 1.35 × 10⁷ | +    | +    | +    | −    | −    | −    | 2.70 × 10⁷ | −    |
| Pseudomonas aeruginosa | WDCM 00025a | 1.40 × 10⁷ | +    | +    | +    | −    | −    | −    | 2.80 × 10⁷ | −    |
| Salmonella enterica subsp. enterica serotype Nottingham | NCTC 7832a | 6.15 × 10⁷ | +    | +    | +    | −    | −    | −    | 1.23 × 10⁸ | −    |
| Stenotrophomonas maltophilia | Sputum | 6.50 × 10⁶ | +    | +    | −    | −    | −    | −    | 1.30 × 10⁷ | −    |
| Yeast |        |         |       |       |       |       |       |       |       |
| Candida albicans | Sputum | 2.10 × 10⁶ | +    | +    | +    | −    | −    | −    | 4.20 × 10⁶ | −    |
| Candida guilliermondii | Sputum | 9.25 × 10⁶ | +    | +    | +    | −    | −    | −    | 1.85 × 10⁷ | −    |

a Reference strain; cfu = colony forming units.
Steam disinfection studies

The “Nuby Natural Touch Steriliser and Dryer” (Model number: BB1022-GS; 220–240V; 50–60 Hz; 650W) (Nuby UK Ltd. Tyne & Wear, UK) domestic steam disinfection device was examined in this study (Fig. 1). The device consists of five components, namely: the Base, Main Body, Lower Tray, Upper Tray and Lid. The lower layer is designed to hold five bottles upside down via locators, with the top layer used for accessories (teat and screw rings). The device can be operated solely in disinfection mode, as well as in disinfection + drying mode (short drying time [15 mins] or long drying time [30 mins]), where in the latter mode, the fan dryer commences 2 min, after the disinfection mode has ended, without any further heating. All steam disinfection studies were performed at GPS Co-ordinates; 54°58’58.99”, −5.942102 (54°35’19.3"’N 5°56’31.6’”W) at an altitude 12 m above sea level. In brief, the device was disassembled and water (90 mls) placed in the heating element reservoir. The device was re-assembled and the cycle started, which lasted approximately 5 min, until all water had boiled off the element. After this, the fan switched on and operated for 0 min (optional fan), 15 min or 30 min. The temperatures reached by the disinfection device were recorded using a combination of integrated probes (Tinytag Ultra 2, TGU-4020 with thermistor probe & Tinytag Ultra 2, TGU-4550 with a type K thermocouple), all which were formally calibrated. All probes had an expanded uncertainty of 0.08 °C and had been recently calibrated by externally to ISO 17025:2005. Probes were placed at various geometrical locations on the upper and lower layers (Fig. 1). Probes were programmed to record the temperature every 20 s using the TinyTag Explorer software (TinyTag UK). Temperatures at several geometric locations within the steam disinfection device were assessed over several cycles, examining the following variables: (i) optimal performance of the disinfection device employing optimal volume of water (90 mls), as per manufacturer’s instructions, (ii) underfilling with water (55 mls and 27.5 mls), (iii) filling reservoir to “maximum” (225 mL) level and (iv) commencing disinfection cycles with water at different temperatures (chilled [6 °C], ambient [19 °C] & boiling [100 °C] water, (v) checking of temperature of upper layer, when lower layer was filled with baby bottles and (vi) filling reservoir to “maximum” level (225 mL) with chilled [6 °C], ambient [19 °C] & boiling [100 °C] water. Thermal disinfection values were calculated based on the A0 concept according to EN ISO 15883 [8].

Steam disinfecter studies – (i) proof of principle

The thermal performance of the steam disinfection device under optimal conditions was checked against 62 isolates, as detailed in Tables 1 and 2. Inocula were constituted as described above and inoculated (100 μl) into sterile 96 well plastic U-bottomed microtitre plates (Sarstedt GmbH, Germany). In addition, two aerobic spore forming organisms, Bacillus cereus (NCTC 10320) and Bacillus subtilis subsp. spizizenii (NCTC 10400) were also included in the study, where B. subtilis was acting as a surrogate for Clostridium difficile, as previously described [9]. Microtitre plates were placed on the top layer of the steam disinfection device (without lids) and a complete disinfection cycle performed (without fan drying) under optimal conditions, in accordance with the manufacturer’s instructions. Following disinfection, inocula were transferred to nutrient broth and cultured as described above. In addition, the device was challenged with volume (mls) of liquid it could successfully disinfect. Nutrient broth volumes [1 ml, 2 mls, 4 mls, 5 mls, 10 mls, 16 mls, 20 mls, 30 mls, 40 mls and 50 mls] were added aseptically to separate 60 mls sterile plastic containers (Sterilin, UK), to which an inoculum of Salmonella enterica subsp. enterica serotype Nottingham (3.08 × 107 cfu) was added. All containers were subjected to 1 complete cycle of disinfection. Following disinfection, containers were incubated at 37 °C for 24h and checked for growth, as described above.

Steam disinfecter studies – (ii) case study – fomite - babies’ dummies

Babies dummies (soothers/pacifiers) were selected to demonstrate the application of the steam disinfection device to the disinfection of an everyday fomite. Unbranded babies’ dummies were purchased from a high street retail shop. These were constructed from hard plastic with a clear silicone angled teat, with a hollow inner core volume (approx. 2.2 ml). All dummies were sterilised by autoclaving at 121 °C/15 min/15psi. Thermal penetration of the

![Figure 1](image-url)
Results

Microbial thermal inactivation studies

Survival of the seven bacteria and two yeasts at the six temperatures are shown in Table 1. All organisms could be recovered from 4 min at 51 °C and 59 °C, but not at 75 °C, 83 °C and 91 °C. At 67 °C, all organisms survived with the exception of Stenotrophomonas maltophilia and S. enterica subsp. enterica serotype Nottingham (Table 1).

Steam disinfector thermal performances studies

The thermal performance of the disinfector unit gave calibrated temperature profiles, as shown, including: (i) optimal performance of the disinfector device employing optimal volume of water (90 mls), in disinfection mode with fan, as well no fan, (Fig. 2 [Upper Layer], Supplementary Fig. 1 [Lower Layer]), (ii) optimal performance of the disinfector device on lower layer with baby bottles (with thermocouples placed inside inverted baby bottle), employing optimal volume of water (90 mls), in disinfection mode with no fan (Table 3), (iii) underfilling with water (55 mls and 27.5 mls) (Supplementary Figure 2), (iv) filling water to "maximum" (225 ml) level (Supplementary Fig. 3a–b) and (v) commencing disinfection cycles with water at different temperatures (chilled [6 °C], ambient [19 °C] & boiling [100 °C] water) (Supplementary Fig. 4a–d). Temperature of upper layer when bottom layer is filled with baby bottles is shown (Table 3). The maximum temperatures achieved at various upper and lower layer locations within the disinfector unit, the duration (time; secs) at temperatures ≥70 °C, ≥80 °C, ≥90 °C and ≥93 °C, as well as the equivalent A0 values obtained are shown (Table 3).

Steam disinfector studies — (i). Proof of principle

All organisms failed to be recovered following a complete steam disinfection cycle. Furthermore, the additional 48 isolates also failed to be recovered. The B. cereus and the B. subtilis subsp. spizizenii isolates failed to be killed by disinfection and were successfully cultured post-disinfection.

S. enterica subsp. enterica serotype Nottingham was not recovered from nutrient broth volumes in all volumes with the exception of 50 mls, where it survived.

Steam disinfector studies — (ii) case study — fomite - babies’ dummies

The inner teat space of the dummies achieved A0 = 600 and a thermal profile (see Supplementary Fig. 5). All organisms tested failed to be recovered from the inner teat space (2 mls) of babies dummies following a complete steam disinfection cycle.

Discussion

This study examined the performance of steam disinfection using a domestic steam disinfector device. Initially, we wished to examine the thermal susceptibilities of four Gram-positive, four Gram-negative and two yeast species (Table 1). Overall, Gram-positive organisms were more heat tolerant, in that they were able to survive temperatures up to 67 °C, whereas half of the Gram-negatives were...
lost at this temperature. The two Candida species were able to survive 67 °C for 4 min. Having established the thermal susceptibility of each species, we then wished to correlate these values against the output of a domestic steam disinfector device. The disinfector unit successfully achieved thermal lethality for the purpose for which it was intended, i.e. baby bottles in the bottle layer ($A_0 = 600$) and teats and rings on the upper layer ($\geq A_0 = 3000$). Thermal performances of the disinfector unit varied however with thermocouple location, where the upper layer always achieved higher $A_0$ values, in comparison to the lower layer (Table 3). Critical negative variation in disinfector performance was noted whenever the unit was underfilled with water (Supplementary Fig. 2), hence it is critical to ensure that the correct volume of water is added to either the recommended fill level (90 mls) or preferably to the maximum fill level (225 mls). With the exception of two aerobic spore-forming organisms, all 62 non spore-forming bacterial and yeasts organisms were killed absolutely, with no survivors detected following extended recovery/enrichment, on completion of steam disinfection in the device.

In a proof-of-concept study, we wished to examine the adoption of steam disinfection to babies’ dummies. Previously, there have been reports of babies’ dummies being associated with infection, as well as outbreaks. These studies have shown that the dummy is an important local factor in the colonization and proliferation of yeast in the oral cavity [10], as well as describing their involvement in an outbreak of yersiniosis due to Yersinia enterocolitica in infants in Tennessee, USA [11] and an outbreak of Elizabethkingia meningoseptica sepsis with meningitis in a well-baby nursery, where dummy storage boxes and covers had identical typing profiles to the clinical isolates [12]. In 2016, a Joint Working Group of the Healthcare Infection Society and Infection Prevention Society published their guidelines on the decontamination of breast pump milk collection kits and related items at home and in hospital [13]. The guidance offered by the Joint Working Group is to discard the dummies every 24h, due to the hollow centre space being inaccessible to robust disinfection. A followup survey published two years later in 2018 demonstrated that there was poor compliance in a neonatal unit in replacing dummies every 24h, due to the cost of replacement [14]. This report also highlighted the presence of four Enterobacteriaceae, including E. coli, Proteus mirabilis and Serratia and Klebsiella species from dummy container lids. These workers highlighted that neonates are particularly vulnerable to colonization and infection with Gram-negative bacteria, including multi-drug resistant strains. It was therefore our aim to evaluate the how steam disinfection may add value to this particular situation. We selected a wide range of Gram-positive and Gram-negative organisms, including several Yersinia organisms, other foodborne pathogens, nosocomial organisms and yeast, as target organisms that may be associated with dummy contamination. We prepared mixtures of these pathogens which we injected into the hollowbulb of sterile dummies and then applied the steam disinfection. Subsequently, we were unable to recover any organisms from the contaminated dummies, even after prolonged cultural recovery/enrichment, demonstrating
the thermal lethality offered by the steam disinfector device. The crucial element of these studies was the attempt to disinfect the volume of liquid inoculum (circa 2 ml) contained within the inner bulb space, which is inaccessible to chemical surface disinfection. This inner void space may backfill and become contaminated with liquid containing pathogens, whenever the bulb is squeezed. Current studies from above demonstrated that the disinfector unit could cope with volumes up to 40 mls, before there was disinfection failure, thus the 2 ml inner volume of the dummy bulb would not present a significant challenge to disinfection in this instance. Given that heat is a physical process, then such inaccessible locations now become accessible thorough heating, as the heat can travel through the plastic/silicone components and disinfect the inner bulb space, given sufficient time/temperature combinations, as calculated above. This study examined the thermal performance of a single brand of steam disinfector and therefore does not extrapolate to other brands. Microbial lethality data is available for another brand of domestic baby bottle disinfector, namely the WabiBaby device (Texas, USA) [15].

The current study examined the principle of applying steam from such a device to eradication of clinically significant pathogens in the home setting. When operated under manufacturer’s instructions, steam disinfection was able to achieve sufficient lethal temperatures to eradicate all Gram-positive, Gram-negative and yeast organisms examined, with the exception of the aerobic spore-forming organisms, which would require a step-up to full sterilization with autoclaving, to ensure spore-former eradication. Variation in temperatures were recorded, depending on the geometric location within the device, where the upper layer always reached ≥99.9 °C and

| Table 3 Thermal performance of steam disinfector using the Ao Concept according to EN ISO 15883. |
| --- |
| Probe position | Maximum temperature reached (°C) | Time (sec) at (A₀ equivalent)  |
| Upper Layer |  | ≥70 °C | ≥80 °C | ≥90 °C | ≥93 °C |
| (i) No Fan; 90 mls fill volume, lower layer empty |  |  |  |  |  |
| 1 | 100.0 | 800 (A₀ = 60) | 600 (A₀ = 60) | 400 (A₀ = 300) | 340 (A₀ = 600) |
| 2 | 100.1 | 820 (A₀ = 60) | 620 (A₀ = 60) | 400 (A₀ = 300) | 320 (A₀ = 600) |
| 3 | 100.5 | 800 (A₀ = 60) | 580 (A₀ = 60) | 400 (A₀ = 300) | 320 (A₀ = 600) |
| 4 | 99.9 | 780 (A₀ = 60) | 580 (A₀ = 60) | 400 (A₀ = 300) | 340 (A₀ = 600) |
| 5 | 100.1 | 800 (A₀ = 60) | 600 (A₀ = 60) | 420 (A₀ = 300) | 340 (A₀ = 600) |
| (ii) Fan [30mins]; 90 mls fill volume, lower layer empty |  |  |  |  |  |
| 1 | 98.0 | 516 (A₀ = 6) | 400 (A₀ = 60) | 280 (A₀ = 600) | 200 (A₀ = 600) |
| 2 | 98.4 | 520 (A₀ = 6) | 400 (A₀ = 60) | 280 (A₀ = 600) | 220 (A₀ = 600) |
| 3 | 99.0 | 500 (A₀ = 6) | 400 (A₀ = 60) | 280 (A₀ = 600) | 240 (A₀ = 600) |
| 4 | 98.1 | 500 (A₀ = 6) | 400 (A₀ = 60) | 280 (A₀ = 600) | 200 (A₀ = 600) |
| 5 | 98.5 | 520 (A₀ = 6) | 420 (A₀ = 60) | 300 (A₀ = 600) | 220 (A₀ = 600) |
| (iii) No Fan; 90 mls fill volume, lower layer filled with baby bottles |  |  |  |  |  |
| 1 | 95.7 | 510 (A₀ = 6) | 300 (A₀ = 60) | 120 (A₀ = 600) | 60 (A₀ = 600) |
| 2 | 96.7 | 510 (A₀ = 6) | 330 (A₀ = 60) | 120 (A₀ = 600) | 60 (A₀ = 600) |
| 3 | 96.7 | 510 (A₀ = 6) | 330 (A₀ = 60) | 150 (A₀ = 600) | 90 (A₀ = 600) |
| 4 | 95.3 | 480 (A₀ = 6) | 270 (A₀ = 60) | 90 (A₀ = 600) | 30 (A₀ = 600) |
| 5 | 96.7 | 510 (A₀ = 6) | 300 (A₀ = 60) | 120 (A₀ = 600) | 60 (A₀ = 600) |
| Lower Layer |  |  |  |  |  |
| (i) No Fan; 90 mls fill volume, lower layer empty |  |  |  |  |  |
| 6 | 89.9 | 460 (A₀ = 6) | 320 (A₀ = 60) | 0 | 0 |
| 7 | 88.8 | 360 (A₀ = 6) | 200 (A₀ = 60) | 0 | 0 |
| 8 | 86.1 | 360 (A₀ = 6) | 180 (A₀ = 60) | 0 | 0 |
| 9 | 93.0 | 480 (A₀ = 6) | 400 (A₀ = 60) | 160 (A₀ = 600) | 1 |
| 10 | 89.6 | 480 (A₀ = 6) | 240 (A₀ = 60) | 0 | 0 |
| (ii) Fan [30mins]; 90 mls fill volume, lower layer empty |  |  |  |  |  |
| 6 | 89.3 | 180 (A₀ = 6) | 60 (A₀ = 60) | 0 | 0 |
| 7 | 88.0 | 260 (A₀ = 6) | 160 (A₀ = 60) | 0 | 0 |
| 8 | 83.5 | 320 (A₀ = 6) | 180 (A₀ = 60) | 0 | 0 |
| 9 | 90.0 | 260 (A₀ = 6) | 140 (A₀ = 60) | 0 | 0 |
| 10 | 89.0 | 380 (A₀ = 6) | 260 (A₀ = 60) | 0 | 0 |
| (iii) No Fan; 90 mls fill volume, inside baby bottles |  |  |  |  |  |
| 6 | 95.2 | 560 (A₀ = 6) | 380 (A₀ = 60) | 220 (A₀ = 600) | 100 (A₀ = 600) |
| 7 | 96.5 | 660 (A₀ = 60) | 480 (A₀ = 60) | 220 (A₀ = 600) | 160 (A₀ = 600) |
| 8 | 95.0 | 640 (A₀ = 60) | 400 (A₀ = 60) | 161 (A₀ = 600) | 79 (A₀ = 600) |
| 9 | 95.3 | 620 (A₀ = 60) | 421 (A₀ = 60) | 200 (A₀ = 600) | 141 (A₀ = 600) |
| 10 | 97.1 | 719 (A₀ = 60) | 559 (A₀ = 60) | 320 (A₀ = 3000) | 241 (A₀ = 3000) |
≥98.0 °C without and with fan, respectively and ≥86.1 °C and ≥83.5 °C, without and with fan, respectively in locations in the lower layer. Additional notable suboptimal reduction in temperatures achieved, occurred due to underfilling of the device with suboptimal volumes of water. These variations resulted in reduced heating of the device, with the potential of allowing pathogens to survive, that would ordinarily be eradicated if the device was operated correctly, hence emphasizing the importance of operating the device under full manufacturer’s guidance. To achieve maximum heat lethality, operationally, we recommend using the upper layer of the device and filling the water reservoir to the maximum permitted volume (225 mls) without fan.

A large variety of medical devices, fomites and other mundane objects may be amenable to disinfection, in support of hospital-at-home. Whether or not a fomite or medical device could be steam disinfected in this manner may be influenced by several factors including (i) the size and configuration of the device i.e. whether or not the fomite being disinfected could physically fit inside the dimensions of a baby bottle disinfector, (ii) the stability of material following repeated steam disinfection, including steam’s effect of its surface properties and (iii) loss of properties and/or functionality of the material being steam disinfected.

Overall, the disinfector reached temperatures to kill all species challenged, with the exception of bacterial sporeformers. Given the increase in the incidence of multidrug resistant Gram negative organisms, especially the Extended Spectrum Beta-Lactamase (ESBL) producers and carbapenemase-producing organisms, future work should examine the fate of these organisms in such devices, as well as including other devices from other manufacturers.

In conclusion, domestic steam disinfection, when performed properly, offers a relatively inexpensive, simple, versatile and widely available technology for the elimination of common nosocomial pathogens and disinfection of medical devices and fomites within the hospital-at-home scenario, thereby enhancing patient safety.

Ethics

This was entirely an in vitro study not involving patients, healthcare staff, any other humans nor animals and as such did not require ethical approval.

Authorship statement

Beverley C. Millar: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing - original draft, Writing - review & editing.

Jonathan Stirling: Formal analysis, Investigation, Methodology, Software, Supervision, Roles/Writing - original draft, Writing - review & editing.

Mollie Maguire: Investigation, Methodology, Writing - review & editing.

Rachel E. Moore: Investigation, Methodology, Writing - review & editing.

Alan Murphy: Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing - original draft, Writing - review & editing.

John E. Moore: Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing - original draft, Writing - review & editing.

Conflict of interest

None of the authors have any conflicts to declare.

Funding

This work was not supported by any external funding.

Provenance and peer review

Not commissioned; externally peer reviewed.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.idh.2020.09.005.

References

[1] Morris DE. Sante´ service Bayonne: a French approach to home care. Age Ageing 1983;12:323–8. https://doi.org/10.1093/ageing/12.4.323.
[2] Shepperd S, Iliffe S. Hospital-at-home versus in-patient hospital care. Cochrane Database Syst Rev 2001;2:CD000356. https://doi.org/10.1002/14651858.CD000356.pub2.
[3] Franzin-Garrec M. Quality of care and risk management in hospital at home services. Soins Chir 2016;61:47–8. https://doi.org/10.1016/j.soin.2016.02.010.
[4] Kampf G, Yoss A, Scheithauer S. Inactivation of coronaviruses by heat. J Hosp Infect 2020;105:348–9. https://doi.org/10.1016/j.jhin.2020.03.025.
[5] Leclercq I, Batéjat C, Burguérié AM, Manuguerra JC. Heat inactivation of the Middle East respiratory syndrome coronavirus. Influenza Other Respir Viruses 2014;8:585–6. https://doi.org/10.1111/irv.12261.
[6] Anon. Guidance on shielding and protecting people who are clinically extremely vulnerable from COVID-19. Public Health England. Available at: https://www.gov.uk/government/publications/guidance-on-shielding-and-protecting-extremely-vulnerable-persons-from-covid-19/guidance-on-shielding-and-protecting-extremely-vulnerable-persons-from-covid-19. [Accessed 14 August 2020].
[7] Tolba O, Loughrey A, Goldsmith CE, Millar BC, Rooney PJ, Moore JE. Survival of epidemic strains of nosocomial- and community-acquired meticillin-resistant Staphylococcus aureus on coins. Am J Infect Contr 2007;35:342–6. https://doi.org/10.1016/j.ajic.2006.10.015.
[8] Röhm-Rodowalde E, Jakimiak B, Chojecka A, Wiercińska O, Ziemba B, Kanclerski K. Recommendations for thermal disinfection based on the A0 concept according to EN ISO 15883. Przegl Epidemiol 2013;67:687. 672.
[9] Diab-Elschahawi M, Führnkranz U, Blacky A, Bachhofner N, Köller W. Re-evaluation of current A0 Value recommendations for thermal disinfection of reusable human waste containers based on new experimental data. J Hosp Infect 2010;75:62–5. https://doi.org/10.1016/j.jhin.2010.01.020.
[10] Mattos-Graner RO, de Moraes AB, Rontani RM, Birman EG. Relation of oral yeast infection in Brazilian infants and use of a pacifier. ASDC (Am Soc Dent Child) J Dent Child 2001; 68:33–6.

[11] Jones TF, Buckingham SC, Bopp CA, Ribot E, Schaffner W. From pig to pacifier: chitterling-associated yersiniosis outbreak among black infants. Emerg Infect Dis 2003;9: 1007–9. https://doi.org/10.3201/eid0908.030103.

[12] Tai IC, Liu TP, Chen YJ, Lien RI, Lee CY, Huang YC. Outbreak of Elizabethkingia meningoseptica sepsis with meningitis in a well-baby nursery. J Hosp Infect 2017;96:168–71. https://doi.org/10.1016/j.jhin.2016.11.018.

[13] Price E, Weaver G, Hoffman P, Jones M, Gilks J, O’Brien V, et al. Decontamination of breast pump milk collection kits and related items at home and in hospital: guidance from a Joint Working Group of the Healthcare Infection Society and Infection Prevention Society. J Hosp Infect 2016;92:213–21. https://doi.org/10.1016/j.jhin.2015.08.025.

[14] Checklin D, Gray J. Microbiological risks of reusing dummies for infants in hospital. J Hosp Infect 2018;99:365–6. https://doi.org/10.1016/j.jhin.2018.03.020.

[15] WABI Steam Sanitizer. Available at: https://wabibaby.zendesk.com/hc/en-us/articles/115001003351-Microbial-Tests. [Last accessed 15 September 2020].