**The effects of different hygiene procedures in reducing bacterial contamination in a model domestic kitchen**

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**Abstract**

**Aims**

Few studies have compared the effectiveness of hygienic cleaning under simulated use conditions. This study compares commonly used and novel cleaning methods for food contact and hand contact surfaces in kitchens.

**Methods and Results**

We report results from two surveys on Norwegian consumers’ cleaning procedures. Laboratory models involving cutting boards, tap handles and mobile phones contaminated with *E. coli* and *S. aureus* were used to compare the hygiene efficacy of commonly used cleaning methods together with new technologies (sprays, single use wipes, and chlorine-based disinfectants). Commonly used cleaning methods produced a mean log10 reduction (LR) in contamination of 1.5-2.5. The efficacy could be improved by drying or including a disinfection step (mean LR 3.1-4.6). Cleaning of mobile phones was common and was improved by including humidity (1.5-1.9 mean LR).

**Conclusions**

In many situations, traditional methods used by consumers may be sufficient to hygienically clean surfaces. However, in some situations, such as where there are infected or immune compromised individuals, or where high risk foods are being handled, hygiene practices resulting in higher LR should be recommended.

**Significance and Impact of Study**

This study demonstrates that data from models simulating use conditions are required to estimate the effectiveness of detergent-based removal practices and how these can be enhanced by inactivation processes such as drying and disinfection to ensure that contamination from foodborne pathogens is reduced to acceptable levels to prevent infection transmission.

**Introduction**

A significant number of foodborne infections are acquired at home. A World Health Organization report concluded that 31% of reported food-borne outbreaks in OECD countries occur in private homes, and improvement of consumer knowledge, attitudes and practice could potentially reduce the burden of foodborne outbreaks (Rocourt et al. 2003)*.* The European Food Safety Authority reported that for the food-borne outbreaks registered in 2013, the most reported setting was “household/domestic kitchen” (38.5 %) (Anonymous 2015 a). A main source of bacterial pathogens at home is raw food ingredients or infected persons preparing food. In England and Wales it is estimated that cross contamination is involved in 39% of foodborne outbreaks (Evans et al. 1998). New microbial challenges, such as norovirus which causes infection at low numbers, or bacteria harboring transferable antibiotic resistance genes raise the question of whether more effective hygienic practices are needed in the domestic environment.

Studies show that bacterial loads in a domestic kitchen are highest after food preparation (Haysom and Sharp 2005). Bacterial transfer to other foods or surfaces easily occurs via hands or hand contact surfaces or equipment like cutting boards, knifes and bowls. Cogan et al. (1999) found that *Salmonella* and *Campylobacter* were spread to 60% of the cutting boards during preparation of naturally contaminated chickens. Using a similar model, Barker et al. (2003) showed how *Salmonella* was also transferredto tap handles and telephones during handling and preparation of contaminated chicken. de Wit et al. (1979) recovered *E. coli* from 60-100% of sites after contaminated chicken was used in food preparation. In another study it was shown that *E. coli* could be transferred from contaminated cutting boards to lettuce, even after overnight storage of the cutting board (Wachtel et al. 2003). Rusin et al. (2002) found that non-porous surfaces as the tap handle and telephone receiver gave the highest bacterial and phage transfer rates to hands. The tap handle is more or less always touched by dirty hands before handwashing. Mobile phones which are now used everywhere, including in kitchens, e.g. for checking recipes may transfer bacteria to hands (Ulger et al. 2009; Badr et al. 2012).

Hygienic cleaning of hand and food contact surfaces is essential to reduce the risk of cross contamination, and it is known that many consumers fail in this regard (Redmond et al. 2004; Røssvoll et al. 2013). Today, a growing number of cleaning products such as detergents in trigger sprays or single use wipes are marketed as rapid and easy alternative cleaning methods. Also disinfectants or antimicrobial detergents are increasingly marketed for use in the domestic kitchen. Neutral electrolyzed water (NEW) which contains chlorine (Chiu et al. 2006; Deza et al. 2007; Handojo et al. 2009; Monnin et al. 2012) is a relatively novel concept for treatment of food or equipment in the food sector, and several devices are already marketed for domestic use.

Although there is some literature on hygiene in the domestic environment, very few studies have asked consumers about their cleaning routines in kitchens, or attempted to assess the relative hygiene efficacy of these practices. In the present study we report results from two surveys on Norwegian consumers’ cleaning procedures. The hygiene efficacy of the most commonly used procedures as well as NEW and hypochlorite treatment were then compared using a model which involved cutting boards, tap handles and mobile phones contaminated by contact with ground beef inoculated with test strains. Selected practices were also tested on biofilms on stainless steel coupons incubated in domestic kitchen sinks.

**Materials and methods**

**Consumer surveys on kitchen hygiene**

Two surveys of consumers’ knowledge of kitchen hygiene were conducted in 2009 and 2012 among 2008 and 1046 Norwegian consumers, respectively. The methodology is described elsewhere (Røssvoll et al. 2012; Røssvoll et al. 2014). The 2009 survey included questions about use and cleaning of cutting boards, while the 2012 survey included questions about cleaning of tap handles and mobile phones.

**Contamination and cleaning in a laboratory model kitchen**

**Preparation of contaminated ground beef**

Vacuum packed beef trimmings (Furuseth, Dal, Norway) with average 14% fat and pH 5.7 were obtained 5 days post mortem. The meat was ground through a 4 mm plate, followed by a 2 mm plate in a combined blender and grinder (ME 130, Seydelmann, Aalen, Germany). The meat was vacuum packed and frozen. The frozen ground beef was thawed for 24 h at 4 °C before inoculation.

Stock cultures of *Escherichia (E.) coli* M23 (non-pathogenic strain with growth characteristics similar to *E. coli* causing disease in humans (Salter et al. 1998)) and *Staphylococcus (S.) aureus* ATCC 6538 were maintained in 20% glycerol at -80°C. For inoculum preparation, frozen suspensions were streaked on tryptic soy agar (TSA; Oxoid Basingstoke, UK), and incubated at 37 °C for 24 h. Each strain was inoculated into 5 ml tryptic soy broth (TSB; Oxoid) and incubated for 18-20 h at 37 °C, 200 rpm. Hundred µl of subcultures were transferred to 50 ml TSB and incubated for 18-20 h at 37 °C, 200 rpm. The cultures were cold adapted at 4 °C for 1 day before being used as inoculum. They were diluted to appropriate concentrations in a 0.9% NaCl solution and blended as 5% suspensions into the ground beef to obtain a concentration of approximately 108 CFU g-1 of both *E. coli* M23 and *S. aureus* ATCC 6538. The contents were mixed thoroughly with hands.The contaminated ground beef was vacuum packed and stored in packs of 500 g at 3 °C until use during the next consecutive six days. Experiments revealed that the number of colony forming units was stable during the storage.

**Contamination model**

Surfaces were low-density polyethylene (PE-LD) cutting boards (Daloplast, Gnosjö, Sweden), chromium-plated tap handles (IKEA, Sweden) and touch-screen mobile phones (Nokia, Finland). Cutting boards were cut in pieces of 12 x 15 cm. Approximately 100 g contaminated ground beef was placed on each of 10 cutting board samples and formed with bare hands into hamburger patties. The contaminated hands were then used to operate the tap handle and the mobile phone (Figure 1). After operating each object, the hands were recontaminated by forming a new hamburger patty, before touching the next object. On each day, the test was conducted using the same batch of contaminated ground beef in conjuction with 10 or six separate sets of tap handles or mobile phones, respectively. Tap handles were mounted on a board for ease of use and cleaning. Before testing, hands were decontaminated by washing thoroughly in warm water using dish water detergent, rinsing, and drying using disposable paper towels, followed by rubbing the dry hands with a liquid alcohol hand sanitizer.

**Cleaning and disinfection agents and utensils**

Cotton woven dish cloths (Unik Universal, Unil AS, Norway), nylon dish washing brushes (Jordan, Oslo, Norway), dish washing detergent (Sunlight, Lilleborg, Oslo, Norway), and single use wipes were purchased from a local supermarket. A new dish cloth was used for each test. Two types of single use wipes were used for cleaning the tap handles; wipe 1 (Jordan Easy Wipe Kjøkken, Lilleborg) and wipe 2 (Jif Oxy wipes, Lilleborg), both containing non-ionic surfactants, and the latter containing H2O2 (concentration not given on label). Wipes used to clean the mobile phones had an ethanol content of 77.4 % (Antibac Pharma, CCS Healthcare AB, Malmö, Sweden). The alcohol-containing wipes were very thin compared to the more “fluffy” single use wipes, which also contained more fluid. A detergent spray (Jif Kjøkken, Lilleborg), containing non-ionic and anionic surfactants was used for cleaning of tap handles. Hypochlorite solution was prepared from a commercial disinfectant (TITAN Hypo, Lilleborg). Neutral electrolysed water (NEW) was freshly prepared each day according to the manufacturer’s instructions using two different devices intended for the consumer market: Stera-Tech (NEW-1, Tokyo, Japan) and, Toucan–eco (NEW-2, Centrego Ltd., Somerset, UK). The devices were not available in Norway at the time and were supplied by an agent considering import . In these devices, electrolysis takes place inside a trigger spray-bottle containing water (0.35 l) and salt (1 g).The chlorine content of the in use solutions was determined with a chlorine detection kit (Dulcotest DT1, Prominent, Heidelberg, Germany). The oxidation reduction potential (ORP) and pH were determined by a Thermo Scientific Orion Star A215 pH/Conductivity Meter (Thermo Fisher Scientific Inc., Waltham, USA). The free available chlorine (FAC) in the NEW-solutions 1 and 2 were 360 and 40 mg l-1, ORP were +860 and +730 mV, and the pH were 9.2 and 8.9, respectively (mean values for all replicates). The measured mean FAC of the hypochlorite solution was 5600 mg l-1.

**Hygienic cleaning tests**

Standardized procedures simulating domestic cleaning practices, as reported in the consumer surveys, were developed. Cleaning with electrolysed water was carried out according to manufacturers instructions. Hypochlorite has been reported to be more effective than detergent-based cleaning, even with rinsing (Barker et al. 2003), but is not commonly marketed or used in domestic kitchens in Norway (Jacobsen and Lavik 2011).

All tests were performed by the same operator. At the end of each day, all surfaces were given a final decontamination. Dish cloths and dish washing brushes were rinsed to remove gross soiling and immersed in boiling water (dish clothes and dish washing brushes were immersed for 5-10 s and 2 s, respectively). For cutting boards, visible gross soiling was removed with a disposable cloth, boards immersed in boiling water and surfaces sprayed with 70 % alcohol. For tap handles and mobile phones, soiling was removed with a disposable cloth and surfaces sprayed with 70 % alcohol. All objects were air dried after decontamination and exposed to UV light (254nm, Ultra-Electric, Oslo, Norway) for 2 h. Hygienic cleaning tests were performed six times on six separate days.

*Hygienic cleaning of cutting boards*

Three contaminated cutting boards were randomly selected as non-treated controls. All 7 hygienic cleaning protocols (listed in Table 1) involved brushing the surface while rinsing using hot (59 °C) tap water. Protocols included cleaning with hot water only and with hot water and detergent. These protocols were also performed followed by air-drying at room temp for 45 mins. Three further boards were treated by spraying with NEW-spray or hypochlorite after cleaning with hot water.

Rinsing was carried out for 6 s with hot (59 °C) tap water at a flow rate of 6 l min-1. The water was allowed to hit the cutting board approximately 4 cm above the contaminated area , and the board was held in a 45° angle to the water flow, a slight modification of the method described by (Wachtel et al. 2003). Boards were brushed with a dish washing brush five times in a downward movement while rinsing. A new dishwashing brush was used for each test. In tests using detergent, 1 ml of dish washing detergent was deposited on the cutting board, approximately 4 cm above the contaminated area and brushed downwards in one stroke, before rinsing and brushing as described above. The NEW-sprays and the hypochlorite were sprayed on the surface of the cutting boards using a trigger spray. Five sprays (in total 2.7, 5.1 and 6.3 g of NEW-1, NEW-2 and hypochlorite solutions, respectively) of the disinfectants were applied to the cutting board surface, with 1 min contact time and sampled without rinsing.

*Hygienic cleaning of tap handles*

An overview of the 9 different hygienic cleaning protocols used on the tap handles is shown in Figure 2. One contaminated tap handle was randomly selected as a non-treated control. Dish cloths were moistened in warm (ca. 50 °C) running tap water and wrung out using gloved hands. Detergent cleaner was prepared using 1 liter warm (ca. 50 °C) tap water with 1 ml dishwashing detergent, in which the dish cloth was wrung out with gloved hands. Wiping the tap handles with the cloth and single use wipes was performed by wiping the entire surface in one stroke only. The hypochlorite solution (3.8 g), NEW-1 (1.6 g) and NEW-2 (3.1 g) were sprayed on the surface of tap handles which had been wiped with H2O moistened cloths. The detergent spray was sprayed once (1.3 g) on the tap handle surface and subsequently wiped off (no specific contact time) with either paper before wiping with a detergent moistened cloth or a H2O moistened cloth.

*Hygienic cleaning of mobile phones*

Six contaminated mobile phones were randomly selected as non-treated controls. The mobile phones were wiped with different cloths/wipes: H2O moistened cloth, detergent moistened cloth, two single use wipes, an alcohol containing wipe and a soft dry cloth (as recommended by the manufacturer). The dish cloths were prepared as described for wiping of tap handles. Only the back side of the mobile phone (5.5 x 11.5 cm) which has closest contact with the hand was wiped and sampled. The wiping technique was performed as described for wiping of tap handles.

**Sampling and microbial analyses**

All Items were sampled by the same operator using flocked nylon swabs (FLOQSwabs, Copan Diagnostics Inc., Murrieta, CA, USA). Swabbing technique was adapted from methods described by Hedin et al. (2010): One swab was moistened in D/E Neutralizing broth (Difco) before rubbing the entire surface of the cutting board, mobile and tap handle (surface area of tap was 10.5 x 2.5 cm) three times. A dry swab was rubbed at a 90 ° angle to the first rub, to absorb as much solution as possible. Both swabs were put into 3 mL D/E Neutralizing broth. After 5 min the tubes were vortexed and the swabs discarded.

The undiluted sample (1 ml) and serial 10-fold dilutions, prepared in PBS were plated on TSA using a Whitley Automatic Spiral Plater (Don Whitley Scientific Ltd., West Yorkshire, UK) and incubated at 30 °C for 48 h.

Preliminary experiments showed that *E. coli* M23 and *S. aureus* ATCC 6538 grew well on TSA with colonies of distinct morphology which could easily be distinguished from each other. The level of natural background flora in the ground meat was 104 g-1 and the number of coliforms 102 g-1. No other types of colonies than the one typical for *E.coli* and *S. aureus* were observed for any of the experiments.

**Effect of hygienic cleaning methods on steel coupons from kitchen sinks**

**Domestic kitchen sink model**

Preliminary experiments with stainless steel coupons (2 x 6 cm, (AISI 304, 2B, Norsk Stål AS, Nesbru, Norway) attached for 3-4 weeks in domestic kitchen sinks in normal use, showed bacterial counts of 105 – 106 cfu per coupon. Nine volunteers attached six coupons in their kitchen sinks for a period of 3 months from January 2013. Coupons were attached to the inner walls of the sink with tape (Supertape, Stokvis tapes, Illinois, USA), placing the coupons in pairs, with space between each pair. One coupon was used as the untreated control.Volunteers were instructed to use their kitchen sinks as normal, but to avoid scrubbing of the coupons. Normal cleaning of the kitchen sink, its walls and the attached coupons with running water, dish washing brush and liquid dish washing detergent was accepted. Volunteers were instructed to remove coupons with gloved hands to avoid contamination, and place each coupon in a sterile polypropylene tube for transportation. Swabs and the coupons were returned to the laboratory and analysed within one hour.

**Effect of hygienic cleaning methods**

Three test coupons from each kitchen were subjected to the following procedures: 1.Wiping with a water moistened dish cloth and applying hypochlorite spray containing 5600 mg l-1 FAC. 2. Applying detergent spray and wiping with a water moistened cloth. 3. Wiping with water moistened dish cloth.

One spray (1.3 g) of the hypochlorite solution was applied to the coupon surface, with 1-min contact time and sampled directly. The detergent spray was sprayed on (1.3 g) and subsequently wiped off. The entire surface of the test coupons as well as the untreated coupons were sampled. Sampling was performed as decribed above for items used in hygienic cleaning tests, but agar plates were incubated at 25 °C for 2-3 days. For identification of bacteria surviving hypochlorite treatment, 20 colonies from each treated coupon were picked randomly from agar plates and subjected to 16S rDNA sequencing and identification. Briefly, universal primers (Nadkarni et al. 2002) were used for 16S rRNA gene amplification (V3-V4) and sequencing. DNA was isolated by lysing single colonies using a microwave oven (Sharp Microwave oven R-5000E). The microwave lysis was performed by scraping a small amount of the colony on the bottom of the PCR well and applying microwave treatment for one minute at max power. Amplification was performed using 0.25 µM of each primer, 10 ul Qiagen multipleks PCR kit (2X) (Qiagen) to a total volume of 20 µl. The cycling conditions, PCR purification and sequencing were performed as described previously (Omer et al. 2015).

**Calculations of hygiene efficacy**

Calculations of mean values and statistical analysis were performed with Minitab (Minitab 17.1.0, 2013) using log10 transformation of cell numbers. The logarithmic reduction (LR) was calculated as LR=log cfu(C) – log cfu(T), where cfu(C) is the number of colony forming units (cfu) on the untreated surface cfu(T) is corresponding cfu on treated surfaces. Treatments resulting in bacterial numbers below the detection limit for all six replicates were not included in the statistical analysis and the LR is reported as >4.5 to >6.1, depending on the bacteria levels in controls. For treatments with a few replicates (1-3) exceeding the detection limit, the detection limit was used as the cfu(T) value for calculating the mean value performing statistical tests. Tukeys test was used for testing statistical significance in multiple comparisons, and ANOVA for testing specific hypotheses (e.g. effect of drying or detergent). Effects with a p-value below 0.05 were considered statistically significant.

**RESULTS**

**Consumer cleaning survey and kitchen hygienic cleaning model**

**Cutting boards**

Of 1938 Norwegian consumers, 67 % used hot water, 54 % used a dish washing brush, 53% used detergent and 53% reported using a dish washing machine when cleaning their cutting boards. Many consumers combined several methods, and 41 % reported using a combination of brush, hot water and detergent. 92% reported to have a dish washing brush in their kitchen.

The mean contamination of minced meat per gram was log10 7.5 *E.coli* and log10 7.9 *S. aureus.* Mean contamination on the cutting boards after preparation of hamburger patties was 5.5 log10 *E. coli* and 5.4 log10 *S. aureus*. Table 1 shows that the LR after brushing with water with or without detergent ranged from 1.6 -2.5, although the differences were non-significant. Subsequent drying produced an increase in reduction, although this was not significant for *S. aureus*. *E. coli* was more sensitive to drying than *S. aureus* (p<0.05). Application of NEW-spray produced reductions similar to those obtained by brushing and rinsing followed by drying. The two NEW sprays were significantly more effective thanbrushing and rinsing for *E. coli* , whilst for *S. aureus* only results for NEW-1 spray were significant. Hypochlorite treatment resulted in the highest reduction with no detectable survivors (detection limit 3 cfu) in most replicates.

**Tap handles**

Of 1026 Norwegian consumers, 88 % had a one-grip tap handle in the kitchen sink and 10 % had a two-grip tap handle. About 74% of the respondents answered that they would use paper and/or a dish cloth to clean the tap handle (Figure 3). Of the respondents using the dish cloth only, 38% would use a cloth wrung up in water with detergent, 32% a moist cloth and 28% would spray with detergent and wipe off with cloth. Among respondents reporting using a combination of paper towel and kitchen cloth, 85% would use the paper towel first. Of respondents reporting using paper towel only, 51% would spray with detergent and wipe off with paper, 32% will use a paper moistened in water. A single use wipe was reported used by 15% of the respondents (not asked about type of wipe).

Mean contamination levels on tap handles before cleaning were 4.6 log10 *E. coli* and 4.5 log10 *S. aureus*. The logarithmic reduction in bacterial numbers after cleaning ranged from 1.7 to 3.5 (Table 1). There were few significant differences between the efficacy of the protocols, but for *E. coli* a significantly higher reduction (p<0.05) was obtained by using a detergent spray wiped off by a cloth, compared to a cloth moistened in water. Disinfection with hypochlorite produced in most cases no detectable survivors for both *E.coli* and *S. aureus* (detection limit 3 cfu per tap handle).

**Mobile phones**

98% of respondents (n = 1046) reported to have a mobile phone and 49 % (n=516) stated to have cleaned their mobile phone. The question about how they cleaned their phone was without given alternatives; respondents were asked to write their response in their own words. The following methods were reported: Disinfection (including alcohol) 39%, wiped with moistened cloth/paper 16%, wiped (no further details) 12%, wiped with detergent moistened cloth/paper 10%, wiped with dry cloth/paper 9%, single-use wipe 9%, blown with air 2% and other treatments 3%.

Mean contamination levels on mobile phones before cleaning were 4.4 log10 *E. coli* and 4.6 log10 *S. aureus*. As shown in Table 1, the logarithmic reduction after cleaning ranged from about 0.4 to 1.8 with few significant differences between methods. The hygiene efficacy of using a soft dry cloth, as recommended by the manufacturer of the mobile phone, was significantly lower (p<0.05) than all the other methods tested

Four of the cleaning procedures were the same for tap handles and mobile phones. Higher (p<0.05) bacterial reduction was observed for tap handles than for mobile phones when using moist cloth wrung in water or detergent containing water, or when single use wipes was used.

**Steel coupons from domestic kitchen sinks**

Contamination levels on stainless steel coupons after removal from sinks, were log10 4.9- 6.4 cfu. As shown in Table 1, wiping with a moist cloth followed by spraying with hypochlorite caused a significant reduction in cfu, while a moist cloth with or without detergent produced no significant reduction. The effect of hypochlorite varied considerably on coupons from different kitchens. From four of the kitchens no surviving bacteria (detection limit 3 cfu, >4.5 LR) were detected, while for two coupons the reduction was 1.4 and 1.8 log10. There was no correlation between the initial number of cfu on control coupons and efficacy of hypochlorite (R=0.2). From four kitchens, bacteria surviving disinfection with hypochlorite were identified by 16S rDNA sequencing. The diversity was high with 19 genera representing more than 5% of the microbiota in at least one kitchen. The bacterial flora surviving disinfection varied between different kitchens. The following genera were present on coupons from two different sinks: *Kocuria, Sphingomonas, Chryseobacterium, Enhydrobacter* and *Brachybacterium .*  The remaining 14 genera were only present in one sink.

**Discussion**

In the food industry, performance criteria for hygienic cleaning are defined, the efficacy is monitored both visually and microbiologically, and actions taken if procedures do not meet the criteria. For consumers, no such criteria exist and only visual cleanliness is monitored. Thus consumer’s food hygiene behaviour is based on the practices learned from parents, friends and the educational system, and information from government health agencies and cleaning product manufacturers.

New microbial challenges, such as pathogens with low infectious doses, like norovirus, or bacteria harboring transferable antibiotic resistance genes, raise the question of whether more effective hygienic practices are now needed for the domestic environment (Bloomfield et al. 2007). Good hygiene practice is important not only for preventing spread of food borne pathogens, but also preventing cross contamination from antibiotic resistance genes (e.g. methicillin-resistant *Staphylococcus aureus* (MRSA) and extended-spectrum beta-lactamase (ESBL) producing *E.coli*) which can be found in raw meats (Lavilla et al. 2008; Vanderhaeghen et al. 2010; Leverstein-van Hall et al. 2011; van Rijen et al. 2014).

From a food safety point of view, the key criteria for promoting new methods and technologies is whether and to what extent they can be shown to be more effective in preventing cross-contamination than traditional methods. The survey showed that many Norwegian consumers use traditional cleaning methods involving textile cloths and brushes, detergent and water. Despite strong marketing of single-use wipes and spray detergents, many consumers are cautious of adopting these new technologies. One reason could be that food hygiene pracices are habitual and retaining old habits requires less cognitive effort. Social norms may also hinder the adoption of new methods (Byrd-Bredbenner et al. 2013). Thus, new technologies cannot only be promoted by referring to efficacy, but should also be convenient, not too expensive, safe and environmentally friendly.

In this study, laboratory models simulating domestic conditions were used to compare traditional practices, with new technologies and practices involving disinfectants. Although standard suspension and surface tests are used to measure the performance of disinfectants (proof of principle), there is little field data on their effectiveness (fitness for purpose) relative to that of traditional cleaning methods.

The most commonly used traditional methods produced a mean LR in contamination between 1.5-2.5 on contaminated cutting boards, tap handles and phones. This is in the same range as reported in other studies (Toiviainen-Laine et al. 2009; Lee et al. 2011; Kim et al. 2012). A major difference between cutting boards and taps, is that cutting boards can be rinsed under running water. It is perhaps surprising that the LR achieved by brushing followed by rinsing of boards was no greater than that produced by wiping taps with a moistened cloth. This may be explained by higher surface roughness of the former. Interestingly there was no significant increase in hygienic cleanliness of cutting boards and taps by use of detergent as opposed to water alone, which suggests that the key part of this process is the physical/mechanical action of brushing or wiping. The efficacy of single use wipes on contaminated tap handles and mobile phones was similar to that of cloths (mean LR 1.5-3.0). Use of a detergent spray and wiping action were slightly more effective in reducing contamination on tap handles (mean LR 2.8 and 3.5). DeVere and Purchase (2007) also found that sprays were more effective than wipes against *E. coli* and *S. aureus* on various types of surfaces, and suggested that this is because sprays allow for larger volumes of liquid to be applied.

Our results suggest that dry cloths are relatively ineffective (0.4-0.9 mean LR) for hygienic cleaning of mobile phones and that the more commonly used cleaning methods (alcohol wipes, single-use wipes, moist cloths or paper) which produced 1.5-1.9 mean LR should be recommended. It may be that the manufacturers are concerned that fluids could harm the electronics in the phone. The efficacy of alcohol wipes, was surprisingly low (1.3, 1.8 mean LR). This might be because the wipes contained very little fluid (2 ml according to label) compared to the other treatments. Howell et al. (2014) showed that using wipes (including a wipe with 70% alcohol and 2% chlorhexidine) for cleaning of iPADs was more effective against *Enterococcus faecium* (VRE) and *S. aureus* (MRSA) than using a dry cloth or a cloth soaked in soap and water.

Unlike taps and mobile phones, wiping of the contaminated steel coupons from kitchen sinks with or without detergent produced no significant reduction in contamination. It is known that mature biofilms are difficult to remove, and require increased mechanical force e.g. brushing rather than wiping. The differences could also be due to the fact that the types of bacteria and soil on the coupons were different from that on the inoculated surfaces.

In summary, for fresh contamination, LR-values between 1.5 and 3 was obtained for all cleaning methods commonly used by consumers and newer methods gave similar reductions in bacterial contamination as the traditional use of moist textile cloths or scrubbing with water and detergent. One advantage of single use wipes is that, if textile cloths are not hygienically cleaned after each use, they may harbor pathogenic bacteria and be a source for cross-contamination (Scott and Bloomfield 1990; Cogan et al. 1999; Chaidez et al. 2014).

An important question is whether the LRs obtained by these practices are sufficient to protect consumers against infection. Setting performance criteria should ideally be science based, but a major problem is lack of data on pathogen levels on surfaces after handling of food and difficulties of defining what may be considered a “safe” level of residual contamination. In recent years quantitative microbial risk assessment (QMRA) has been applied to estimate the LR of contamination on surfaces needed to reduce the infection risk to an acceptable level to prevent infection transmission. In a recent study, Ryan et al. (2014) used, data from the published literature for each of 7 microbial species to estimate infection risks for a scenario where a contaminated surface was touched with the fingers, and the fingers then touched the mouth, nose or eyes. The analysis suggested that on average a 2 LR was sufficient to achieve the 10-6 safety target level (deemed as the acceptable daily risk for drinking water) for *E.coli* and *Listeria monocytogenes*, whilst norovirus required an LR of 3.4. For *Pseudomonas* spp., *Salmonella* spp., and *S. aureus* it was estimated that no decontamination process was required. One should note that *S. aureus* was regarded as a skin infection pathogen and not a food borne pathogen or a potential contributor to spread of antibiotic resistance in the analyses. Foodborne intoxications by *S. aureus* are not reported among the communicable diseases in many countries however, in a study from The Netherlands, intoxications from *S. aureus* were the most common cause of food borne disease (Havelaar et al. 2012). Ryan et al. (2014) point out however, that the estimations should be considered as approximate since, in many cases, the input data were uncertain or lacking. In addition, the QMRA estimate was based on data for ambient concentrations of bacteria and viruses on surfaces which were of the order of less than 50 cfu cm-2, which would not be applicable when a person is ill and actively shedding pathogens, or is immune-compromised, or where a *Campylobacter*-contaminated chicken is placed onto a kitchen surface, situations which are not uncommon in a domestic household. Cogan et al. (2002) reported that after preparing chickens naturally contaminated with *Salmonella* and/or *Campylobacter*, 1.7% and 20% of kitchen surfaces contained >1000 cfu per surface area (tap handle, cutting board etc.), and 4.2 and 29% of surfaces contained >100 cfu, respectively. More than 100 cfu cm-2 *E. coli* and *Staphylococcus aureus* were found on respectively 5% and 85% of the kitchen taps in domestic kitchens in Portugal (Azevedo et al. 2014)*.*

It may be concluded that although traditional methods used by consumers to hygienically clean surfaces (e.g. rinsing and brushing with hot water and detergent) may be sufficient in many cases, in some situations, such as where there are infected or immune-compromised individuals, or where high risk foods are being handled, hygienic practices resulting in higher LR should be recommended.

The results suggest that even small changes in practice could increase hygiene efficacy. By introducing a drying step (45 min at room temperature) a significant increase in hygiene efficacy was achieved (mean LR 3.1-4.6). As found by other investigators (Kramer et al. 2006; Møretrø et al. 2010) the gram negative organism *E. coli* was more sensitive to drying than the gram positivie *S. aureus*. However, Cogan et al. (1999) found that, after preparation of *Salmonella* and *Campylobacter*-contaminated chickens using a cutting board, these organisms could still be isolated from the surface 3h later. Studies indicate that efficacy is also increased by using higher water temperatures. Wachtel et al. (2003) found no significant effect of rinsing cutting boards contaminated with *E. coli* O157:H7 in water at 35°C, compared with the 2.0-2.5 LR obtained in this study using water at 59°C. de Jong et al. (2008) observed a 3-4 higher LR of *C. jejuni* and *L. casei* on cutting boards using water at 68°C compared to 10°C.

Disinfection can increase the LR beyond that achievable by detergent-based cleaning alone (Cogan et al. 1999; Barker et al. 2003). The present study indicates that use of the chlorine-based disinfectant, NEW, increases hygiene efficacy (1 to 2 log increase in LR) on cutting boards compared to that obtained using a cloth or brush with detergent. For tap handles, the increase was not significant. No difference in efficacy was observed between NEW-1 and NEW- 2, despite the tenfold difference in hypochlorite concentration (360 and 40 mg l-1, respectively). It has previously been reported that the biocidal effect of NEW is similar to that of hypochlorite solution at the same available chlorine concentration (Park et al. 2005; Deza et al. 2007).

As expected, cleaning and spray disinfection with hypochlorite at 5600 mg l-1 (bleach sprays marketed for domestic hygiene in some European countries mostly contain 5000 mg l-1) was significantly more effective than NEW spray and other methods, and reduced contamination to undetectable levels on both boards and taps (equivalent to >4.5 to >5.9 mean LR). Using a laboratory model, Barker et al. (2003) showed that the number of contaminated hand and food contact sites after handling and preparation of a salmonella-contaminated chicken followed by cleaning and disinfection with 5000 mg l-1 or 500 mg l-1 hypochlorite (1 min contact) was reduced to 2.9% and 31.4% respectively. These various results suggest that, for effective hygienic cleaning of contaminated food contact surfaces, NEW systems which generate higher chlorine concentrations are required. It was observed that running the NEW-1 systems three consecutive times increased the chlorine concentration to 1700 mg l-1 FAC. An argument for promoting use of NEW is that consumer handling of concentrated bleach is avoided.

Washing with detergent was not sufficient to remove sink biofilm and the efficacy of hypochlorite varied considerably in different kitchens with 4 coupons showing no detectable survivors and 2 coupons showing residual contamination (LR 1.4 and 1.8). Mechanical energy is often required to remove biofilms, and a two-step approach with a combination of detergents and brushing followed by disinfection with hypochlorite could increase hygiene efficacy.

Whereas disinfection is recommended and applied in the food and catering industries, use of disinfectants in the domestic environment is controversial. Skeptics argue against disinfectant use in homes on the grounds that they are not necessary (i.e. the risks in the home are less) and concerns about resistance build up and toxicity of biocides. Attitudes to biocides vary between countries. In the Nordic region food authorities and the UK Food Standards Agency advise against disinfection in domestic kitchens (Anonymous 2015b; e; d; c). At present, many European experts advocate that the decision to recommend use of a disinfectant should be based solely on the level of health risk, i.e. they should only be used in high risk healthcare situations where there is an infected or immune –compromised person. This study suggests that we should start by deciding what safety target level is appropriate for a given situation and then deciding how this can be achieved i.e. whether it is achievable by cleaning alone, or whether a disinfectant is needed to reach the target level.

Set against our growing understanding of the extent to which the different components of our environment (including hands) contribute to infection spread, the current approach to breaking the chain of infection is rather unscientific and is becoming the weak link, preventing us from maximising protection against foodborne illness. In public and domestic situations, there is pressure to deliver hygiene in a manner which is both effective and sustainable i.e. involves prudent usage of detergents, water, energy and of antimicrobial agents. Data from models such as those used in this investigation are required to understand how inactivation (disinfectants, drying) and removal (detergent-based cleaning and rinsing) processes can work synergistically to optimise LRs on hands and surfaces. They are also required for developing new approaches which optimize hygienic cleaning of surface attached and biofilm cells, including new cleaning and disinfection agents, and new technologies.

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**CONFLICT OF INTEREST**

No conflict of interest declared.

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**Figure legends**

**Figure 1.** Kitchen contamination and cleaning model. Minced meat contaminated with *E. coli* and *S. aureus* was formed with hands to hamburger patties on cutting boards. The resulting contaminated hands transferred the bacteria to tap handles and mobile phones. The contaminated items were subjected to different cleaning procedures.

**Figure 2**. Overview of hygienic cleaning procedures of tap handles. NEW; neutralized electrolyzed water.

**Figure 3.** Survey results for cleaning of tap handle. A total of 1026 consumers reported their cleaning routines for dirty tap handles. Numbers indicate sum of responses for the different cleaning alternatives. Text within frame, indicate cleaning method selected for testing in kitchen model. Alternatives with <12 responses are not shown.

**Table 1.** Mean log reductions in *S. aureus* and *E.coli* on surfaces following traditional cleaning methods and new technologies and disinfectants

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | Mean Log 10 reduction | | | | | | |
| Treatments | Cutting board  (N=6)† | | Tap handle  (N=6) | | Mobile phone  (N=6) | | Sink  (N=9) |
|  | EC\* | SA | EC | SA | EC | SA | SM |
| **Recommended for mobile phone** |  |  |  |  |  |  |  |
| Dry soft cloth |  |  |  |  | 0.9a | 0.4a |  |
| **Most frequently used methods** |  |  |  |  |  |  |  |
| Wipe with H2O moist cloth |  |  | 1.7a | 1.8a | 1.7a | 1.9b | 0.4a |
| Wipe with detergent and H2O moist cloth |  |  | 2.1ab | 2.0a | 1.8a | 1.5b | 0.6a |
| Brush with running H2O | 2.5a‡ | 2.0ab |  |  |  |  |  |
| Apply detergent, brush with running H2O | 2.3a | 1.6a |  |  |  |  |  |
| **“New” technologies** |  |  |  |  |  |  |  |
| Wipe with single use wipe 1 |  |  | 2.1ab | 2.1a | 1.7a | 1.5b |  |
| Wipe with single use wipe 2 |  |  | 3.0ab | 2.6a | 1.9a | 1.8b |  |
| Spray with detergent, wipe with paper and detergent moist cloth |  |  | 3.1ab | 3.0 a |  |  |  |
| Spray with detergent, wipe with H2O moist cloth |  |  | 3.5b | 2.8a |  |  |  |
| **Effects of drying** |  |  |  |  |  |  |  |
| Brush with running H2O, 45 min air dry | 4.6b | 3.1bc |  |  |  |  |  |
| Apply detergent, brush with running H2O, 45 min air dry | 4.5b | 3.3bc |  |  |  |  |  |
| **Disinfection with NEW spray** |  |  |  |  |  |  |  |
| Wipe with H2O moist cloth + spray NEW-1 |  |  | 2.4 ab | 2.6a |  |  |  |
| Wipe with H2O moist cloth + spray NEW-2 |  |  | 2.8ab | 2.6 a |  |  |  |
| Brush with running H2O, spray NEW-1 | 4.5b | 4.1c |  |  |  |  |  |
| Brush with running H2O, spray NEW-2 | 3.9b | 3.3bc |  |  |  |  |  |
| **Disinfection with hypochlorite or alcohol** |  |  |  |  |  |  |  |
| Alcohol wipe |  |  |  |  | 1.8a | 1.3ab |  |
| Brush with running H2O, spray hypochlorite | NDS§ | NDS |  |  |  |  |  |
| Wipe with H2O moist cloth, spray hypochlorite |  |  | NDS | NDS |  |  | 1.4-NDS¶ |

\*EC; *E. coli*, SA; *S. aureus*, SM; sink microflora. NEW; neutral electrolyzed water

†Number of replicates

‡ Numbers within a column not sharing any of the letters a,b,c are significantly different (p<0.05).

§NDS; No detectable survivors, the number of surviving bacteria was below the detection limit (3 cfu), corresponding to LR >4.5 to >6.1, depending on the bacteria levels in controls.

¶The range in LR is given