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Efficacy of instant hand sanitizers against foodborne pathogens compared to hand washing with soap and water in food preparation settings: a systematic review

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1 Running title: Efficacy of hand sanitizers in food preparation setting

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4 **Efficacy of instant hand sanitizers against foodborne pathogens compared to**
5 **hand washing with soap and water in food preparation settings: a systematic**
6 **review**

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22 soiled hands

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26 **ABSTRACT**

27 Hands can be a vector for transmitting pathogenic microorganisms to foodstuffs and
28 drinks, and to the mouths of susceptible hosts. Hand washing is the primary barrier
29 to prevent transmission of enteric pathogens via cross-contamination from infected
30 persons. Conventional hand washing involves the use of water, soap and friction to
31 remove dirt and microorganisms. Over recent years there has been an increasing
32 availability of hand sanitizing products for use when water and soap are unavailable.
33 The aim of this systematic review was to collate scientific information on the efficacy
34 of hand sanitizers compared to hand washing with soap and water for the removal of
35 foodborne pathogens from the hands of food handlers. An extensive literature search
36 was carried out using three electronic databases - Web of Science, Scopus and
37 PubMed. Twenty-eight scientific publications were ultimately included in the
38 systematic review. Analysis of the literature showed various limitations in the
39 scientific information due to the absence of a standardized protocol to evaluate
40 efficacy of hand products, and variation in experimental conditions applied in
41 different studies. However, despite the existence of conflicting results, scientific
42 evidence seems to support the historical scepticism about the use of water-less hand
43 sanitizers in food preparation settings. Water and soap appear to achieve greater
44 removal of soil and microorganisms than water-less products from hands. Alcohol-
45 based products achieve rapid and effective inactivation of various bacteria, but their
46 efficacy is generally lower against non-enveloped viruses. The presence of food
47 debris significantly affects inactivation rates of hand sanitizers.

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Foodborne disease via consumption of contaminated food and beverages is considered one of the most common causes of human disease all around the world (45). Norovirus, non-typhoidal *Salmonella* spp. *Listeria monocytogenes*, *Clostridium perfringens*, *Campylobacter* spp. and *Toxoplasma gondii* are the foodborne pathogens most commonly reported in the USA, causing 9.4 million episodes of foodborne illness, 55,961 hospitalizations and 1,351 deaths (53). In the UK, the Food Standards Agency estimates there are more than 500,000 food poisoning cases each year, caused by *Campylobacter* spp. which is responsible for about 280,000 cases each year, followed by *Clostridium perfringens* with about 80,000 cases, Norovirus with about 74,000 cases and *Salmonella* which is responsible for the highest number of hospitalizations, about 2,500 each year (27). More than 320,000 cases of foodborne zoonotic disease are annually reported in the European Union. The most common microorganisms causing foodborne diseases in this region are *Campylobacter* spp., *Salmonella* spp. and viruses such as hepatitis A virus and norovirus (17). Among 31 different microorganisms causing foodborne diseases, five foodborne pathogens, known as the "Top 5", have been identified by food safety experts as highly infective agents that can easily be transmitted by infected food handlers and cause severe illness. The top five foodborne pathogens include: Norovirus, *Salmonella* Typhi (typhoid-like fever), *Escherichia coli* O157:H7 or other Enterohaemorrhagic and Shiga toxin-producing *E. coli*, *Shigella* spp., and Hepatitis A virus (25). Greig et al. (2007) reviewed a total of 816 reports of foodborne outbreaks from United States, Canada, Europe, Australia and identified 14 agents responsible for most of outbreaks where food workers were implicated. The 14 main agents were Norovirus (or probable Norovirus), *Salmonella enterica*, Hepatitis A virus,

76 *Staphylococcus aureus*, *Shigella* spp., *Streptococcus* Lancefield A and G and
77 parasites like *Cyclospora*, *Giardia* and *Cryptosporidium* (30).

78 The origins of pathogenic microorganisms in food include the food itself or its
79 source, such as the growing, harvesting or processing environment, as well as
80 cross-contamination and infected food handlers. In industrialized countries infected
81 food handlers have been identified as an important cause of foodborne illness (4, 31,
82 33). Estimates suggest that up to one third of outbreaks in Ireland (4) and 12% of
83 outbreaks in the United Kingdom (19) are caused by infected employees. Another
84 study of foodborne illness outbreaks in restaurants in the United States identified
85 food handling by infected workers as the main factor contributing to around two-
86 thirds (65%) of foodborne illness outbreaks (33). Food service facilities including
87 restaurants and catered events are the settings where most food worker associated-
88 outbreaks occur (56), and contact with bare hands and failure to properly wash
89 hands were the most frequently reported factors contributing to outbreaks (57). In
90 light of this, good personal hygiene and safe food handling practices are essential for
91 preventing foodborne illness.

92 Hand washing for hand hygiene is the most important practice to prevent the
93 spread of pathogens (6). Hand washing with water and soap is generally considered
94 to be the gold standard method to remove dirt and transient microorganisms from
95 hands. Plain soaps have minimal or no antimicrobial activity against bacteria and
96 viruses, but by surfactant action, friction and final rinsing under water can effectively
97 remove dirt, soil and microbial load from the outer layer of hand skin (39, 60). Over
98 the past two decades, increasing interest has been placed on the use of hand
99 cleansing products possessing antimicrobial activity, like antimicrobial soaps, or
100 instant hand sanitizers including both alcohol-based and alcohol-free preparations.

Antimicrobial soaps are preparations containing both a detergent and antiseptics or disinfectants with antibacterial activity, such as Triclosan, Chlorhexidine gluconate (CHG) or Para-chloro-meta-xlenol (PCMX). Antimicrobial soaps are considered to be effective against Gram positive microorganisms, to have moderate activity against viruses and tubercle bacilli, but to be less effective against Gram negative microorganisms (34, 39).

Alcohol-based hand sanitizers, or alcohol-based hand rubs (ABHRs), are instant hand hygiene products; the antimicrobial activity of which is due to the ability of alcohol to denature protein. These products usually contain a quantity of alcohol, varying from 60% to 95%, and a thickening agent or humectants such as polyacrylic acid, glycerin, or propylene glycol to decrease the drying effect of alcohol. ABHRs have documented microbiological activity against bacteria (21, 51), fungi and some enveloped viruses including HIV, herpes, adenovirus, influenza and parainfluenza viruses (20). Lower efficacy against non-enveloped “naked” viruses is generally reported in the literature, and the level of inactivation seems to vary a lot depending on the viruses tested, type of alcohol, concentration, and time of exposure (12, 20, 21, 29, 32, 49, 50, 52).

Finally, another group of instant hand products known as alcohol-free hand sanitizers, such as povidone-iodine-, triclosan- or quaternary ammonium-based compounds, has also attracted growing interest over recent years. Despite being historically recognised as less effective than ABHRs, more recent formulations prepared with benzalkonium chloride (BZK) have demonstrated many advantages over ABHRs including residual antimicrobial activity after use, less drying effect on hand skin, and lack of decrease in efficacy after repeated use (13).

Use of water-less hand sanitizers as an alternative to conventional hand washing has long been debated. Despite some potential advantages over conventional water and soap (quicker and easier usage), instant hand products are generally considered to more effectively meet needs in hospital and health-care, rather than food preparation, settings. ABHRs containing 60% to 95% alcohol are recommended as an alternative to hand washing in hospital and health-care settings when hands are not visibly soiled (5). In contrast, their use in food establishments has historically been refused because of their inability to remove fat and food debris from soiled hands (23). To date, little research has been conducted to examine the efficacy of hand disinfectants against transient microorganisms normally occurring on food workers' hands during food preparation. This systematic review was carried out to examine the performance of different hand hygiene products against foodborne pathogens in food preparation settings.

MATERIALS AND METHODS

An extensive literature review was conducted in November 2014 using the electronic databases Web of Science, Scopus and PubMed. The search was limited to articles published in English from 1990 to 2014. Search terms used were: "efficacy of hand washing", "efficacy of hand sanitizers", "evaluation of hand sanitizers", and "effect of hand hygiene products".

Three preliminary criteria were adopted to select journal papers. Only articles that described levels of inactivation of foodborne pathogens (the actual pathogens not surrogate microorganisms), used a research approach with quantitative outcomes, and described studies undertaken in industrialized countries, were included in this study. In contrast, all book chapters, studies carried out on microorganisms not

involved in foodborne illness, studies involving inactivation of foodborne microorganisms from raw food or food contact surfaces were excluded before analysis, based on the title and abstract.

Once preliminary results matching search terms were obtained, data extraction was carried out in three steps. Firstly, duplicate articles were identified and removed. Secondly, remaining titles and abstracts were screened for eligibility against inclusion criteria. Thirdly, full text articles were retrieved and assessed in terms of their study design and scientific approach. All articles identified were then critically reviewed by the authors and included as appropriate to provide an overview of the topic.

RESULTS

From amongst 2108 records originally matching the search terms, 38 unique journal abstracts were preliminarily screened for eligibility after duplicates were removed. Subsequent analysis of full text journal articles permitted selection of the 28 journal articles that are included in this review (Table 1). Among the selected studies testing hand washing products against foodborne pathogens, ten papers provided information on Norovirus, three on Hepatitis A virus, two on *Listeria monocytogenes*, fourteen on *Escherichia coli*, eight on *Staphylococcus aureus* and one on *Salmonella* spp. No scientific information was found for other pathogenic bacteria like *Campylobacter* spp. and *Bacillus cereus*.

Besides the use of conventional water and soap or water only, products more generally tested against pathogenic bacteria and viruses included antibacterial liquid soaps, alcohol-based hand sanitizers and non-alcohol based sanitizers including triclosan-, chlorhexidine gluconate- (CHG), povidone-iodine- and quaternary

ammonium-based products like benzalkonium chloride (BZK) or benzethonium chloride (BZT), 5-pyrrolidone-2-carboxylic acid (PCA) and copper sulphate pentahydrate (CS). Hand washing practices considered also included use of soap and nailbrush (40), *Wash-sanitise*, consisting of using hand sanitizers after hand washing with water and soap (15, 30, 47), and a new hand hygiene regime known as *SaniTwice* (a registered trademark of James Mann, Handwashing for Life, Libertyville, IL) consisting of a two stage hand cleansing including application of an excess of alcohol-based sanitizer, hand rubbing, cleaning hands with a paper towel, and a final application of alcohol-based sanitizer (14).

The relative efficacy of products was generally tested *in vitro*, *ex vivo* and/or *in vivo*. Most of the *in vitro* studies involved experiments carried out using a suspension assay consisting of a standardized quantity of the target microorganism treated with increasing concentrations of the test product, with the aim of estimating the inactivation rate for each product used (1, 10, 16, 20, 21, 28, 29, 54, 46, 55). One *in vitro* study evaluated inactivation rates of tested products on latex gloves immersed in a solution of phosphate buffered saline (PBS) or crab cooking water artificially contaminated with 5 log₁₀ CFU *L. monocytogenes*/ml (44). *Ex vivo* tests included experiments carried out on pig skin from a freshly killed pig (the pig skin method) previously treated with sanitizing products, then artificially contaminated with challenge microorganisms to test residual activity of tested products after use (9, 28, 35, 54). *In vivo* studies involved experiments carried out with selected human volunteers to estimate the efficacy of each tested product to remove or inactivate target microorganisms from artificially contaminated whole hands, finger pads or gloves. The vast majority of *in vivo* studies retrieved in the literature were carried out on hands or finger pads artificially contaminated with pure cultures of bacteria or

viruses without the presence of food components or organic material (9, 16, 22, 29, 37, 38, 41, 42, 43, 47, 55). Seven studies evaluated the efficacy of hand washing products in a food preparation setting on naturally and artificially soiled hands or gloves (7, 8, 14, 15, 40, 44, 48). Three studies evaluated inactivation rates of products on hands contaminated with viral suspensions prepared with other organic loads like fetal bovine serum or feces (15, 36, 40). Other factors pertaining to food preparation settings like hygiene of nails (40) and wearing rings when handling food have also been minimally considered (61). A summary of the experimental conditions applied and main findings from *in vitro*, *ex vivo* and *in vivo* evaluations in all studies included in this review are summarized in Table 2. Information relating to specific pathogens will now be summarised.

Norovirus. Because human norovirus (HuNoV) cannot be routinely cultured *in vitro*, determining the effectiveness of sanitizers and disinfectants against HuNoV is difficult. Methodologies used to estimate level of virus reduction include the use of reverse transcription-quantitative real time PCR to quantify the number of RNA copies of HuNoV extracted and purified from tested samples (41, 42, 46) and the use of cultivable surrogates like Feline Calicivirus (FCV) and Murine Norovirus (MNV). Norovirus surrogates were generally tested alone as an alternative to HuNoV (9, 15, 29, 36, 38, 40, 55), or in parallel with HuNoV (46).

Liu et al. (41) compared the efficacy of an antibacterial soap, alcohol-based sanitizer containing 62% ethyl alcohol, and water rinsing for the removal of HuNoV from artificially contaminated finger pads. Ethanol-based hand sanitizer was the least effective hand product tested ($0.34 \pm 0.22 \log_{10}$ reduction). The greatest $\log_{10}$ reduction was observed for water rinse only ($1.38 \pm 0.49 \log_{10}$) and antibacterial soap ($1.1 \pm 0.49 \log_{10}$). A separate study by Liu et al. (42) tested various commercially

available hand hygiene products containing 62% to 95% alcohol on finger pads against multiple HuNoV strains. The study showed a wide range of efficacy (0.10 to 3.74 log₁₀ reduction), varying according to different products and strains tested. The highest level of RNA reduction was achieved by a 70% ethanol gel containing additional ingredients that seem to potentiate the virucidal activity of alcohol alone. A limitation of the study reported by the authors was the presence of PCR inhibitors in the test products that may have affected PCR amplification and led to an overestimate of virus reduction.

Eight papers evaluated the efficacy of hand sanitizers against FCV and MNV. Experimental methods used to estimate viral inactivation included a virus-specific cytopathic effect (CPE) test consisting of culturing post treatment samples on a serial dilution of permissive host cells (9, 15, 29, 36, 38, 40, 55), and a plaque assay test in parallel with TaqMan real-time reverse transcription PCR (46). Park et al. (46) evaluated *in vitro* virucidal efficacy of seven hand sanitizers containing ethanol, triclosan and chlorhexidine against both Norovirus surrogates (i.e. FCV and MNV) and human norovirus (HuNoV). None of the products demonstrated significant RNA reduction when tested against HuNoV, whereas results achieved for Norovirus surrogates showed different levels of viral reduction measured by plaques assay and RT-qPCR. A general lack of correlation between the two detection methods and different degrees of viral inactivation of FCV or MNV were generally observed. Only a 72% alcohol pH 2.9 ABHR reduced the infectivity of both FCV and MNV (3.4 and 2.6 log₁₀, respectively) by the plaque assay test, whereas no correlation was found between reduced infectivity and RNA reduction measured by real-time reverse transcription PCR.. Conflicting results were also reported in two studies evaluating both *in vitro* and *in vivo* efficacy of hand products against FCV and MNV. Gehrke et

250 al. (29) tested three types of alcohol - ethanol, 1- propanol and 2-propanol. *In vitro*
251 experiments showed higher effectiveness achieved by 50% and 70% 1-propanol
252 (10^4 -fold reduction) over ethanol and 2-propanol. In contrast, 70% ethanol achieved
253 higher viral inactivation ($3.78 \log_{10}$ reduction) *in vivo* than either 1-propanol or 2-
254 propanol (3.58 and $2.15 \log_{10}$ reduction, respectively). Steinmann et al. (55)
255 compared virucidal activity of three ABHRs and three antimicrobial soaps. Results
256 from suspension tests demonstrated $\geq 5 \log_{10}$ reduction of both FCV and MNV
257 achieved by two of three ABHRs tested which was greater efficacy than soaps
258 tested (typically $\leq 3 \log_{10}$ reduction). Conversely, the modified finger pad test carried
259 out against MNV only, showed superior antimicrobial activity of a povidone-iodine
260 soap ($4.62 \log_{10}$ reduction) compared to the other ABHRs and soaps tested. Two
261 studies evaluated *in vivo* efficacy of hand hygiene products against FCV only. Lages
262 et al. (38) tested four ABHRs, three non-alcoholic sanitizers and two triclosan-
263 containing antimicrobial liquid soaps after 30 s and 2 min exposure times. Limited
264 efficacy of all the products tested was generally observed; only one antimicrobial
265 soap containing 10% povidone-iodine ($\leq 2.67 \log_{10}$ reduction) and one ABHR
266 containing 95% ethanol ($\leq 1.30 \log_{10}$ reduction) achieved appreciable viral reduction
267 compared to water rinse tested in parallel. Czerwinski and Cozean (9) compared a
268 novel hand sanitizer containing benzethonium chloride (BZK), a 62% ABHR, an
269 antibacterial liquid soap, and water rinse. Apart from a promising level of inactivation
270 shown by the novel hand sanitizer ($3.49 \log_{10}$ reduction), generally viral reductions
271 were $< 1 \log_{10}$ in all the other cases. Two studies evaluated efficacy of products on
272 hands artificially contaminated with a fecal suspension of FCV. Kampf et al. (36)
273 tested efficacy of three ABHRs; greatest reduction in FCV was achieved by a 95%
274 alcohol containing hand sanitizer ($2.17 \pm 1.06 \log_{10}$). Lower concentrations of alcohol

275 did not demonstrate more than 1 log₁₀ viral reduction. Lin et al. (40) compared six
276 hand washing practices on contaminated natural and artificial nails. Use of soap and
277 nail brush (2.54±0.57 log₁₀ reduction) achieved the highest log₁₀ viral reduction,
278 followed by hand washing with antibacterial soap (2.26±0.42 log₁₀ reduction), and
279 then combined use of soap and hand sanitizer (2.13± 0.93 log₁₀ reduction). In
280 contrast, the use of hand sanitizer alone demonstrated limited efficacy (0.86±55 log₁₀
281 reduction). Presence of long nails on treated hands was found to significantly impact
282 efficacy of all the hand products tested. Finally, one study carried out by Edmonds et
283 al. (15) compared four hand hygiene regimes on hands contaminated with a viral
284 suspension of MNV prepared with 0.5% fetal bovine serum to mimic soiling with
285 organic matter. Hand hygiene practices included an antimicrobial soap, a 70%
286 alcohol gel, hand washing followed by hand sanitizing, and SaniTwice. Sanitizing
287 with 70% alcohol gel was slightly more effective (2.6±0.41 log₁₀ reduction) than hand
288 washing with antimicrobial soap (1.79±0.29 log₁₀ reduction). A higher level of viral
289 reduction was achieved by SaniTwice (4.04±0.33 log₁₀) and by the combination of
290 conventional hand washing and sanitizing (3.19±0.31 log₁₀).

291 **Hepatitis A virus (HAV).** Little information is available in the scientific literature
292 about relative effectiveness of hand washing products against HAV. Only three
293 studies describing efficacy of hand washing products against HAV were retrieved
294 (20, 21, 43). Fendler et al. (21) and Fendler & Groziak (20) demonstrated limited *in*
295 *vitro* efficacy of a commercially available alcohol-based hand sanitizer containing
296 62% alcohol and emollients against HAV. The levels of inactivation achieved by 30 s
297 timed exposure were 1.75 and 1.25 log₁₀ reduction, respectively, corresponding to
298 94.37% (21) and 94.4% (20) reduction of original inoculum.

A study by Mbithi et al. (43) evaluated elimination rates of 10 different products on whole hands or finger pads artificially contaminated with a mixture of viruses and feces. Formulations tested included a non-medicated soap, five ethanol-based hand sanitizers, and four antibacterial liquid soaps, compared to tap water without soap used as a control. None of the tested products reached a level of inactivation of 99.9%, which is generally desired. Inactivation rates observed from both whole-hand and finger pad methods ranged from 79% to 94%. One antibacterial soap and non-medicated soap attained a higher level of virus reduction ($\leq 94.56 \pm 5.75\%$ and $\leq 91.39 \pm 2.65\%$, respectively) than alcohol based hand sanitizers ($\leq 90.67 \pm 2.08\%$) and tap water ($\leq 81.57 \pm 4.5\%$). Residual infectivity, estimated as a mean number of Plaque Forming Units through a plaque assay test, ranged from 0 to 0.64 PFU for ABHRs, 0.63 to 1.74 PFU for antimicrobial soaps, 1.57 PFU for plain soap and 3.88 PFU for tap water. No information was found in the literature about the efficacy of hand washing and hand sanitizers against HAV on hands soiled with food components.

Listeria monocytogenes. Only two papers describing *in vitro* and *in vivo* efficacy of sanitizing products against *L. monocytogenes* were found in the literature (21, 44). Fendler et al. (21) reported $> 5 \log_{10}$ reduction of *L. monocytogenes* achieved *in vitro* by a commercially available hand sanitizer containing 62% alcohol on a 30 s timed exposure kill test. McCarthy (44) compared the *in vivo* efficacy of one hand sanitizer and five disinfectants, including two chloride-based, one iodine-based, one peroxide-based, one quaternary ammonium-based sanitizer, on contaminated latex gloves. The impact of the organic compounds on inactivation rates of the tested products was estimated through immersion of gloves in both sterile phosphate buffered saline (PBS) and crab cooking water artificially contaminated with $5 \log_{10}$ CFU/ml of *L.*

324 *monocytogenes*. Of the different products tested, only the peroxide-based product
325 achieved 5 log₁₀ reduction of attached *L. monocytogenes* on both soiled and non-
326 soiled contaminated gloves. The two chloride-based and the quaternary ammonium-
327 based products achieved 5 log₁₀ reduction on gloves contaminated with PBS
328 suspensions of *L. monocytogenes* (i.e. no food residue present) but demonstrated
329 lower efficacy ($\leq$ 1-2 log₁₀ reduction) in the presence of crab cooking water. Iodine-
330 based sanitizer and alcohol-based instant hand sanitizer demonstrated lower
331 efficacy in both cases. No data about the efficacy of conventional hand washing in
332 removing *L. monocytogenes* from gloves or hands was found in the literature.

333 ***Staphylococcus aureus* and *Escherichia coli*.** Six studies assessed *in vitro*
334 and/or *ex vivo* efficacy of hand sanitizers against *St. aureus* and *E. coli*. Hand
335 formulations included conventional ABHRs and new generation hand products
336 containing a combination of active antimicrobials and other compounds like
337 thickening agents, emollients and natural compounds. Fendler et al. (21) reported
338 that > 5 log₁₀ reduction was achieved by a 62% alcohol based sanitizer against both
339 methicillin-resistant and vancomycin-tolerant and methicillin-resistant *St. aureus*,
340 non-pathogenic *E. coli* and *E. coli* O157:H7. High *in-vitro* inactivation rates were also
341 reported by Biagi et al. (1), Czerwinski et al. (10), Gaonkar et al. (28), Kaiser et al.
342 (35), and Shintre et al. (54). Biagi et al. (1) tested the *in vitro* efficacy of a new
343 combination of two natural compounds, pyrrolidone-2-carboxylic acid (PCA) and
344 copper sulphate pentahydrate (CS). The combination of PCA and CS demonstrated
345 higher efficacy than 70% ethanol and 60% isopropanol used alone. Czerwinski et al.
346 (10) tested the efficacy of a novel alcohol-based antiseptic and a novel water-based
347 antiseptic lotion prepared with a synergistic combination of ingredients centred on
348 Benzethonium chloride (BZT). The novel water-based product demonstrated

equivalent antimicrobial (99.9%) activity against *E. coli* and *St. aureus* strains compared to the other alcohol-based product. Gaonkar et al. (28) tested an ABHR prepared with an emollient (Octoxy) and other additional ingredients against *E. coli* and methicillin-resistant *St. aureus*. *In vitro* evaluations showed $> 7 \log_{10}$ reduction of both *E. coli* and *St. aureus* and *ex vivo* tests showed higher antimicrobial activity and superior residual activity after use of the novel Octoxy compared to the two other ABHRs applied in parallel as a control. Kaiser et al. (35) compared *ex vivo* a combination of a surgical scrub containing 4% Chlorhexidine gluconate (CHG) and ABHRs prepared with and without thickening agents against *St. aureus*. Hand sanitizers thickened with anionic polymers were found to negatively impact persistent activity of CHG. In contrast, no negative effect was observed for ABHRs alone or thickened with non-ionic compounds. Shintre et al. (54) tested the synergistic effect of alcohol and quaternary ammonia in combination with moisturizers or essential oils *in vitro* and *ex vivo*. Synergistic combination of farnesol and BZT demonstrated better prolonged activity (i.e. 20-35 min post application) against *St. aureus* and *E. coli* than other hand sanitizers and chemicals compounds used alone.

The high level of bacterial inactivation generally observed *in vitro* does not necessarily reflect the actual capacity of products to remove transient microorganisms from the outer layers of skin of hands. Incomplete effectiveness against target microorganisms from cleaned hands is generally reported in all studies carried out on hands artificially contaminated with *E. coli*. Edmonds et al. (16) compared the efficacy of two novel 70% alcohol gel and foam, seven commercially available ABHRs, and two World Health Organization recommended formulations containing 60-90% alcohol against one methicillin-resistant *St. aureus* strain. Results showed superior efficacy of the novel gel and foam preparations after single and

multiple uses compared to the other products. However none of the products exceeded 3 log₁₀ reduction of the target microorganism. Fishler et al. (22) evaluated the effectiveness of two hand washing regimes in reducing transient bacteria after single wash and subsequent potential transfer of bacteria to a ready-to-eat food. The antimicrobial soap achieved a higher level of bacterial removal (>3 log₁₀ reduction) than plain soap (≤2 log₁₀ reduction), but failed to avoid the transfer of seeded bacteria to a ready-to eat food item. Kampf et al. (37) reported limited efficacy of two ABHRs on hands artificially contaminated with *E.coli*. Bacterial inactivation achieved by two 62% alcohol containing products was only slightly better (≤3.5±0.45 and 3.58±0.71 log₁₀ reduction) than rubbing under running water applied in parallel (2.39±0.57). Paulson et al. (47) examined the abilities of four hand washing regimes including plain soap, an antimicrobial soap, an alcohol hand sanitizer, and combined use of an antimicrobial soap and a ABHR (used after hand washing). All the products used alone performed equally and none exceeded 2 log₁₀ reduction. Higher efficacy (3.28 log₁₀ reduction) was observed by combined use of hand washing and hand sanitizing.

***Salmonella* spp.** Little information about the efficacy of sanitizing products against *Salmonella* spp. is available in the literature. Only one *in vitro* study (21) reporting > 5 log₁₀ reduction of *Salmonella* Enteritidis and *Salmonella* Typhimurium being achieved by a 62% ABHR was retrieved.

Efficacy of hand products on hands soiled with food components.

Experimental conditions described in the literature to mimic food preparation settings include contamination of food workers hands with natural soil encountered in the food service industry (7), or hands artificially inoculated with pure cultures of bacteria mixed with crab cooking water (44), chicken or beef broth (14, 15, 40), ground beef

399 (7, 14, 15, 40), dirt or cooking oil (48). Efficacy of hand products was estimated
400 based on the enumeration of microorganisms released from treated hands, or based
401 on the enumeration of bacteria remaining on hands. Methods for enumerating
402 released bacteria included the glove juice (14, 15, 61) or the hand rinse (8, 48)
403 techniques. Both techniques consist of enumerating bacteria released from washed
404 hands previously placed into a glove or a bag filled with sterile water or buffer.
405 Conversely, enumeration of bacteria remaining on the hands after hand washing or
406 hand sanitizing is usually estimated through image analysis or by pressing washed
407 hand palms onto the surface of an agar plate (7).

408 Four studies compared efficacy of hand hygiene products on soiled hands.
409 Courtenay et al. (8) compared eliminating abilities of three hand washing regimes
410 including rinsing with warm water, rinsing with cold water and hand washing with
411 water and soap on hand and gloves contaminated with *E. coli* and ground beef.
412 Water and soap achieved a higher level of removal than other hand hygiene
413 regimes, but the level of bacterial removal was higher from hands (99.98%) than
414 from gloves (99.13%). The efficacy of four hand sanitizers containing 62% ethanol
415 was also compared on clean hands contaminated with $10^6 \log_{10}$ cfu of *E. coli*/ml of
416 broth. The level of bacterial reduction achieved by the four hand sanitizers ranged
417 from 96.44 - 90.40% and was consistently lower than that observed for water and
418 soap. Charbonneau et al. (7) tested eliminating abilities of a plain soap, a 70%
419 alcohol hand sanitizer, and combined use of hand washing and ABHS on hands
420 naturally contaminated with raw chicken and ground beef. The study showed higher
421 efficacy achieved by plain soap over the other hand hygiene regimes. Limited
422 efficacy of ABHRs on clean hands or hands soiled with dirt and oil was also reported
423 in a study by Pickering et al. (48). Bacterial reduction achieved did not exceed $2 \log_{10}$

of seeded *E.coli* (10^7 CFU/ml) in all cases. Efficacy of hand hygiene practices in moderately and heavily soiled conditions has been evaluated in two studies (14, 15). Edmonds et al. (15) demonstrated superior efficacy of combined use of water and soap and hand sanitizing than water and soap or antimicrobial soap used alone. Reported levels of bacterial inactivation achieved from both moderately and heavily soiled hands were >5.0 and $>4.6 \log_{10}$ reduction, respectively. Edmonds et al. (14) tested eliminating capacity of SaniTwice carried out with three 62% to 70% alcohol products compared to a plain soap, an antibacterial soap and a 70% alcohol gel used alone. SaniTwice with 70% alcohol foam showed higher efficacy than water and soap and other alcohol-based regimes. The level of bacterial reduction observed on moderately and heavily soiled hands was 4.61 and 3.92 $\log_{10}$, respectively. Heavy soil condition was found to impact efficacy of all the practices tested ($<1-2 \log_{10}$ reduction).

Other considerations in relation to effective hand cleansing. Only two studies evaluated the efficacy of hand washing techniques in the removal of bacteria or viruses from natural and artificial nails (40) or from hands with rings present (61). Wongworawat et al. (61) compared the efficacy of three hand sanitizers, including a povidone-iodine, a water-aid alcohol and an alcohol-chlorhexidine hand sanitizer, on hands with and without rings. The alcohol-chlorhexidine hand sanitizer showed slightly higher efficacy than other products. No significant difference in the number of bacteria retrieved from cleansed hands with and without rings was generally observed. Results reported suggest that the presence of rings should not significantly impact effectiveness of hand sanitizers.

Lin et al. (40) assessed effectiveness of different cleansing products and hand practices from natural and artificial nails on hands inoculated with *E. coli* or FCV.

Use of a nailbrush and soap achieved the highest removal of target microorganisms. However the presence of long nails significantly impacted efficacy of all regimes tested, suggesting that maintaining short fingernails is essential to reduce the risk of transmitting hazardous microorganisms when handling food.

DISCUSSION

Effective hand washing is extremely important to help prevent harmful microorganisms from spreading from people's hands to food. Contact with bare hands and failure to properly wash hands have been reported as the main risk factor contributing to foodborne disease caused by food handlers (57). European Union food safety legislation requires every person working in a food handling area to maintain a high standard of personal cleanliness, and food business operators to provide an adequate number of washbasins suitably located and designed for cleaning hands (18). The Food Code 2009, published by the Food and Drug Administration to standardize food safety and food hygiene procedures, states that the total time recommended for proper hand washing is at least 20 seconds, of which 10-15 seconds should be used for rubbing followed by rinsing under running warm water and drying hands (24).

The presence of food components like fat, oil or other dirt is considered the main factor affecting removal and inactivation rates of hand hygiene products against microorganisms occurring on the hands of food workers (26). The levels of microbial contamination reported for hands of food workers can vary between 2 and $>5 \log_{10}$ cfu/hand across various food settings, and the bacterial flora generally encountered on the hands of food handlers is a mixture of Enterobacteriaceae and other mesophilic bacteria in the presence of fat and other soil (11). Various pathogens with

very low infective doses (1 to 100 units) including viruses, parasites and enteric bacteria can be present on contaminated hands in high numbers (58). Pathogens carried by contaminated hands can be easily transferred to food and hand contact surfaces and can survive for long periods (58, 59). The ideal hand hygiene regime to be used in a food setting should ensure maximum removal of food components and food flora from cleaned hands in order to minimize the level of transferable microorganisms. Most of the hand disinfectants, including medicated soaps and instant hand sanitizers, have a broader antimicrobial activity than plain soaps but are generally considered not to properly meet the needs of food workers because they are unable to remove food soil from cleansed hands (23).

This systematic review evaluated the scientific information available in the literature about the efficacy of conventional and improved hand hygiene products in relation to their use in food preparation settings. Analysis of the literature showed the existence of conflicting reports about the efficacy of soaps and hand sanitizers against foodborne pathogens. No standardized method to estimate removal and inactivation rates of target pathogens seems to be available and the varying experimental conditions (including quantity of product used, duration of treatment, type of food soil used) between different studies makes comparison of results difficult. Hand washing with water and soap is generally reported to achieve effective removal of bacteria and soil from hands (7, 8, 14, 15) and gloves (8) and to be superior to other products in the removal of bacteria and viruses from fingernails when used with a nailbrush (40). However, a residual level of microorganisms even after proper washing is generally reported (7, 8, 14, 15, 40), suggesting that hand washing alone cannot ensure elimination of risk in relation to bacterial transmission from hands to food. Conventional hand washing is more effective on contaminated

hands than on gloves (8) suggesting that frequent changes of gloves rather than washing gloves when they become visibly soiled would more effectively minimize risk of bacterial contamination between different food preparation steps.

Information on the efficacy of antimicrobial soaps over conventional plain soaps is also controversial and the existence of conflicting results has been previously reported in two other reviews (31, 60). Apart from one study reporting lower efficacy compared to plain soap (47), the evidence seems to indicate that antimicrobial or medicated soaps can achieve a slightly higher level of microbial inactivation on artificially contaminated hands without food residue present (22, 43), whereas their efficacy on soiled hands is similar to conventional soaps (15, 40).

Instant hand sanitizers have shown high and rapid *in vitro* efficacy against various target bacteria (10, 16, 21, 54), whereas their efficacy against naked viruses seems to be lower (20, 21, 38, 46) and vary according to different viruses tested, type of alcohol and concentration used (29, 46, 55). These findings are in general agreement with four other reviews (2, 3, 31, 60). Apart from some improved formulations (9, 32), instant hand sanitizers used *in vivo* do not usually exceed 2-3 log₁₀ microbial reduction (16, 37, 41, 42, 47, 48) and their efficacy seems to be affected by the presence of food debris, as observed on both moderate (44) and heavily soiled hands (7, 14, 40), as only one study included in this systematic review reported similar rates of bacterial inactivation on both clean and soiled hands (48). Instant hand sanitizers used alone seem not to be a reliable substitute for conventional hand washing in food establishments (7). In contrast, their application after hand washing, previously carried out with either antimicrobial or plain soap (i.e. wash-sanitize regimes), seems to be more effective than hand sanitizer or soaps used alone (15, 47); levels of bacterial inactivation have been demonstrated to

significantly increase up to 4 or 5 log₁₀ reduction on both moderately and heavily soiled hands (15).

Preliminary results reported for SaniTwice are also encouraging (14). The method tested on hands moderately and heavily soiled with a mixture of food components and *E. coli* showed good levels of bacterial reduction (~4 log₁₀ reduction). A similar level of inactivation is also reported against MNV on artificially contaminated hands. These findings suggest that this hand hygiene regime could be used as an alternative to wash-sanitize when water and soap are not available. However, no evidence about the efficacy of this hand hygiene regime against HuNoV or HAV on soiled hands seems to be available in the literature. For this reason, further studies would be needed to prove the effectiveness of SaniTwice in different food settings and against different foodborne pathogens.

Finally, a new generation of alcohol-free lotions is attracting more and more interest (1, 28, 35). Evidence from *in vitro* and *ex vivo* studies showed similar efficacy against target bacteria compared to alcohol-based products, with prolonged activity after application, and potentially less skin irritation. However, very little is known about their efficacy against viruses, and no evidence about their inactivation rates on soiled hands seems to be available in the literature currently.

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REFERENCES

1. Biagi, M., D. Giachetti, E. Miraldi, and N. Figura, 2014. New non-alcoholic formulation for hand disinfection. *J. Chemo.* 26(2):86-91.
2. Bloomfield, S.F., A.E. Aiello, B. Cookson, C. O' Boyle, and E.L. Larson, 2007. The effectiveness of hand hygiene procedures in reducing the risks of infections in home and community settings including hand washing and alcohol-based hand sanitizers. *mJ. Infect. Control.* 35(10) supplement 1:S27-64
3. Bloomfield, S.F. and EA Scott, 2013. A risk assessment approach to use of antimicrobials in the home to prevent spread of infection. *Am. J. Infect. Control.* 41: S87-93.
4. Bonner, C., B. Foley, and M. Fitzgerald, 2001. Analysis of outbreaks of infectious intestinal disease in Ireland: 1998 and 1999. *Ir. Med. J.* 94(5):365-372.
5. Centers for Disease Control and Prevention (CDC), 2002. Guidelines for hand hygiene in health-care settings: recommendation of the Healthcare Infection Control Practices Advisory Committee and the HICPA/SHEA/APIC/IDSA Hand Hygiene Task Force. *Morb. Mort. Week. Rep.* 51:1-56.
6. Centers for Disease Control and Prevention (CDC), 2009. Vessel Sanitation Program - OPRP - General information on Hand Hygiene. Available at: http://www.cdc.gov/nceh/vsp/cruiselines/hand_hygiene_general.htm Accessed on 3 February 2016..
7. Charbonneau, D.L., J.M. Ponte, and B.A. Kochanowsky, 2000. A method of assessing the efficacy of hand sanitizers: use of real soil encountered in the food service industry. *J. Food Prot.* 63(4):495-501.

- 571 8. Courtenay, M., L. Ramirez, B. Cox, I. Han, X. Jiang, and P. Dawson, 2005.
572 Effect of various hand hygiene regimes on removal and/or destruction of
573 *Escherichia coli* on hands. *Food Serv. Technol.* 5:77-84.
- 574 9. Czerwinski, S.E., and J. Cozean, 2012. An evaluation of a hand sanitiser product
575 to reduce norovirus cross infection. *Brit. Global Trav. Health Assoc.* 20:42-46.
- 576 10. Czerwinski, S.E., J. Cozean, and C. Cozean, 2014. Novel water-based antiseptic
577 lotion demonstrates rapid, broad-spectrum kill compared with alcohol antiseptic.
578 *J. Infect. Publ. Health* 7(3):199-204.
- 579 11. De Wit, J.C., and E.H. Kampelmaker, 1981. Some aspects of microbial
580 contamination of hands of workers in food industries. *Zentral. Fur Bakteriол.*
581 *Mikrobiol. Hyg.* 172:290-300.
- 582 12. Duizer E, P Bijkerk, B Rockx, A De Groot, F Twisk, and M Koopmans, 2004.
583 Inactivation of caliciviruses. *Appl. Environ. Microbiol.* 70: 4538-43.
- 584 13. Dyier, D.I., K.B. Gernraich, and P.S. Wadhams, 1998. Testing a new alcohol-free
585 hand sanitizer to combat infection. *AORN J.* 68(2):239-241.
- 586 14. Edmonds, S.L., J. Mann, R.R. McCormack, D.R. Macinga, C.M. Fricker, J.M.
587 Arbogast, and M.J. Dolan, 2010. SaniTwice: a novel approach to hand hygiene
588 for reducing bacterial contamination on hands when soap and water are
589 unavailable. *J. Food Prot.* 73(12):2296-2300.
- 590 15. Edmonds, S.L., R.R. McCormack, S.S. Zhou, D.R. Macinga, and C.M. Fricker,
591 2012. Hand hygiene regimens for the reduction of risk in food service
592 environments. *J. Food Prot.* 75(7):1303-1309.
- 593 16. Edmonds, S.L., D.R. Macinga, P. Mays-Suko, C. Duley, J. Rutter, W.R. Jarvis,
594 and J.W. Arbogast, 2012. Comparative efficacy of commercially available

595 alcohol-based rubs and World Health Organization-recommended hand rubs:
 596 formulation matters. *Amer. J. Infect. Cont.* 40:532-525.

597 17. European Food Safety Authority (EFSA) 2011. EFSA explains foodborne
 598 disease: Food-borne zoonosis. ISBN number: 978-92-9199-384-0. Fact sheet
 599 available at: <http://www.efsa.europa.eu/en/topics/factsheets/factsheetfoodborne>
 600 [zoonoses](http://www.efsa.europa.eu/en/topics/factsheets/factsheetfoodborne) Assessed on 3 February 2016..

601 18. European Parliament, 2004. Regulation (EC) No 853/2004 of the European
 602 Parliament and of the Council, of 29 April 2004, on the hygiene of foodstuffs.
 603 *Off. J. Eur. Union* L 139/1, 30/4/2004.

604 19. Evans HS, Madden P, Douglas C, Adak GK, O' Brien SJ, Djuretic T, Wall PG
 605 and , Stanwell-Smith R. 1998. General outbreaks of infectious intestinal disease
 606 in England and Wales: 1995 and 1996. *Comm. Dis Pub. Health* 1(3): 165-71.

607 20. Fendler, E., and P. Groziak, 2002. Efficacy of alcohol-based hand sanitizers
 608 against fungi and viruses. *Infect. Cont. Hosp. Epidemiol.* 3(2):61-62.

609 21. Fendler, E.J., Y. Ali, B.S. Hammond, M.K. Lyons, M.B. Kelley, and N.A. Vowell,
 610 2002. The impact of alcohol hand sanitizer use on infection rates in an extended
 611 care facility. *Amer. J. Infect. Cont.* (30)4:226-232.

612 22. Fischler, G.E., J.L. Fuls, E.W. Dail, M.H. Duran, N.D. Rodgers, and A.L.
 613 Waggoner, 2007. Effect of hand wash agents on controlling the transmission of
 614 pathogenic bacteria from hands to food. *J. Food Prot.* 70(12):2873-2877.

615 23. Food and Drug Administration (FDA), 2009. Food Code 2009 Chapter 2 -
 616 Management and Personnel - 2-301-16 Hand Antiseptics: Available at:
 617 [http://www.fda.gov/Food/GuidanceRegulation/RetailFoodProtection/FoodCode/u](http://www.fda.gov/Food/GuidanceRegulation/RetailFoodProtection/FoodCode/cm181242.htm)
 618 [cm181242.htm](http://www.fda.gov/Food/GuidanceRegulation/RetailFoodProtection/FoodCode/cm181242.htm). Accessed on 3 February 2016.

- 619 24. Food and Drug administration (FDA) 2009 Chapter 2 - Management and
620 personnel - Ams and Hands - 2-301-12 Cleaning procedures. Available
621 at:[http://www.fda.gov/Food/GuidanceRegulation/RetailFoodProtection/FoodCode](http://www.fda.gov/Food/GuidanceRegulation/RetailFoodProtection/FoodCode/ucm181242.htm)
622 [/ucm181242.htm](http://www.fda.gov/Food/GuidanceRegulation/RetailFoodProtection/FoodCode/ucm181242.htm)
- 623 25. Food and Drug Administration (FDA), 2014. Foodborne Illness. Available at:
624 [http://www.fda.gov/food/guidanceregulation/retailfoodprotection/industryandregul](http://www.fda.gov/food/guidanceregulation/retailfoodprotection/industryandregulatoryassistanceandtrainingresources/ucm113827.htm#foodborne_illness)
625 [atoryassistanceandtrainingresources/ucm113827.htm#foodborne_illness](http://www.fda.gov/food/guidanceregulation/retailfoodprotection/industryandregulatoryassistanceandtrainingresources/ucm113827.htm#foodborne_illness)
626 Accessed on 3 February 2016.
- 627 26. Food and Drug Administration (FDA), 2014. FDA Fact Sheet on Hand Hygiene in
628 Retail and Food Service Establishments. Available at:
629 [http://www.fda.gov/Food/GuidanceRegulation/RetailFoodProtection/Industryand](http://www.fda.gov/Food/GuidanceRegulation/RetailFoodProtection/IndustryandRegulatoryAssistanceandTrainingResources/ucm135577.htm)
630 [RegulatoryAssistanceandTrainingResources/ucm135577.htm](http://www.fda.gov/Food/GuidanceRegulation/RetailFoodProtection/IndustryandRegulatoryAssistanceandTrainingResources/ucm135577.htm) Accessed on 3
631 February 2016.
- 632 27. Food Standards Agency (FSA) 2014. New UK food poisoning figure published.
633 Available at: [https://www.food.gov.uk/news-updates/news/2014/6097/food](https://www.food.gov.uk/news-updates/news/2014/6097/food-poisoning)
634 [poisoning](https://www.food.gov.uk/news-updates/news/2014/6097/food-poisoning) Accessed on 3 February 2016.
- 635 28. Gaonkar, T.A., I. Geraldo, L. Caraos, and S.M. Modack, 2005. Efficacy of hand
636 rubbing containing a synergistic combination of emollient and preservatives;
637 prolonged activity against transient pathogens. *J. Hosp. Infect.* 59:12-18.
- 638 29. Gehrke, C., J. Steinmann, and P. Goroncy-Bermes, 2004. Inactivation of Feline
639 Calicivirus, a surrogate of Norovirus (formerly Norwalk-like viruses), by different
640 types of alcohol in vitro and in vivo. *J. Hosp. Infect.* 56:49-55.
- 641 30. Greig, J.D., E.C.D. Todd, C.A. Barleson, and B.S. Micheals, 2007. Outbreaks
642 where food workers have been implicated in the spread of foodborne disease.

- 643 Part 1. Description of the problem, methods, and agents involved. *J. Food Prot.*
644 70(7): 1752-1761
- 645 31. Guzewich, J., and M. Ross, 1999. Evaluation of risks related to microbial
646 contamination of ready to eat food by food preparation workers and the
647 effectiveness of interventions to minimize those risks. White Paper, Section One.
648 A literature review pertaining to foodborne disease outbreaks caused by food
649 workers 1975-1998. Food and Drug Administration, Centre for Food Safety and
650 Applied Nutrition, September 1999. Available at:
651 http://handwashingforlife.com/files/rte_fd_prep_risk_eval.pdf Accessed on 3
652 February 2015.
- 653 32. Hammond B, Y Ali, E Fendler, M Dolan, and S Donovan, 2000. Effect of
654 handsanitizer use on elementary school absenteeism. *Amer. J Infect Control.* 28:
655 340-6.
- 656 33. Hedberg, C.W., S.J. Smith, E. Kirkland, V. Radke, T.F. Jones, C.A. Selman, and
657 the EHS-Networking group, 2006. Systematic environmental evaluations to
658 identify food safety differences between outbreak and non-outbreak restaurants.
659 *J. Food Prot.* 69(11):2697-2702.
- 660 34. Jones, R.D., H.B. Jampani, L. Jerry, J.L. Newman, and A.S. Lee, 2000.
661 Triclosan: a review of effectiveness and safety in health care setting. *Amer. J.*
662 *Infect. Cont.* 28:184-196.
- 663 35. Kaiser, N., D. Klein, P. Karanja, Z. Greten, and J. Newman, 2009. Inactivation of
664 chlorhexidine gluconate on skin by incompatible alcohol hand sanitizing gels.
665 *Amer. J. Infect. Cont.* 37(7):569-573.

- 666 36. Kampf, G., D. Grotheer, and J. Steinmann, 2005. Efficacy of three ethanol-based
667 hand rubs against Feline Calicivirus, a surrogate virus for Norovirus. *J. Hosp.*
668 *Infect.* 60:144-149.
- 669 37. Kampf, G., S. Marschall, S. Eggerstedt, and C. Ostermeyer, 2010. Efficacy of
670 ethanol-based hand foams using clinically relevant amounts: a cross-over
671 controlled study among healthy volunteers. *BMC Infect. Dis.* 10:78.
- 672 38. Lages, S.L., M.A. Ramakrishnan, and S.M. Goyal, 2008. *In-vivo* efficacy of hand
673 sanitisers against Feline Calicivirus: a surrogate for Norovirus. *J. Hosp. Infect.*
674 68(2):159-163.
- 675 39. Larson, E.L., 1995. APIC guidelines for hand washing and hand antisepsis in
676 health care settings. *Amer. J. Infect. Cont.* 149:2749-2753.
- 677 40. Lin, C.M., F.M. Wu, H.K. Kim, M.P. Doyle, B.S. Michaels, and L.K. Williams,
678 2003. A comparison of hand washing techniques to remove *Escherichia coli* and
679 Caliciviruses under natural or artificial fingernails. *J. Food Prot.* 66(12):2296-
680 2301.
- 681 41. Liu, P., Y. Yuen, H.M. Hsiao, L.A. Jaykus, and C. Moe, 2010. Effectiveness of
682 liquid soap and hand sanitizer against Norwalk virus on contaminated hands.
683 *Appl. Environ. Microbiol.* 76(2):394-399.
- 684 42. Liu, P., D.R. Macinga, M.L. Fernandez, C. Zapka, H.M. Hsiao, B. Berger, J.W.
685 Arbogast, and C.L. Moe, 2011. Comparison of the activity of alcohol-based hand
686 rubs against human Norovirus using finger pad method and quantitative real-
687 time PCR. *Food Environ. Virol.* 3:35-42.
- 688 43. Mbithi, J.N., V.S. Springthorpe, S.A. Sattar, 1993. Comparative *in vivo*
689 effectiveness of hand-washing agents against Hepatitis A virus (HM-175) and
690 Poliovirus type1 (Sabin). *Appl. Environ. Microbiol.* (59)10:3463-3469.

- 691 44. McCarthy, S.A., 1996. Effect of sanitizers on *Listeria monocytogenes* attached to
692 latex gloves. *J. Food Safety* 16:231-237.
- 693 45. National Institute of Allergies and Infectious disease (NIAID), 2014. Food borne
694 diseases. Available at: [https://www.niaid.nih.gov/topics/foodborne/Pages/default.
695 \[aspx\]\(https://www.niaid.nih.gov/topics/foodborne/Pages/default.aspx\)](https://www.niaid.nih.gov/topics/foodborne/Pages/default.aspx) Accessed on 3 February 2016.
- 696 46. Park, G.W., L. Barclay, D. Macinga, D. Charbonneau, C.A. Pettigrew, and J.
697 Vinjé, 2010. Comparative efficacy of seven hand sanitizers against Murine
698 Norovirus, Feline Calicivirus, and GII.4 Norovirus. *J. Food Prot.* 73(12):2232-
699 2238.
- 700 47. Paulson, D.S., C. Riccardi, C.M. Beausoleil, E.J. Fendler, M.J., Dolan, L.V.
701 Dunkerton, and A.W. Ronald, 1999. Efficacy evaluation of four hand cleansing
702 regimes for food handlers. *Dairy Food Environ. Sanit.* 19(10), 680-684.
- 703 48. Pickering, A.J., J. Davis, and A.B. Boehm, 2011. Efficacy of alcohol-based hand
704 sanitizer on hands soiled with dirt and cooking oil. *J. Water Health* 9(3):429-433.
- 705 49. Rabenau HF, G Kampf, J Cinati, and HW Doerr, 2005. Efficacy of various
706 disinfectants against SARS coronavirus. *J. Hosp. Infect.* 61:107-11.
- 707 50. Rotter, M.L., 1996. Alcohol for antisepsis of hands and skin. In: Ascenzi, J.M.,
708 ed., *Handbook of Disinfectants and Antiseptics*. New York: Marcel Dekker, pp.
709 177-233.
- 710 51. Rotter, M., 1999. Hand washing and hand disinfection. In: Mayhall C.G., ed.,
711 *Hospital Epidemiology and Infection Control*, 2nd edition. Philadelphia: Lippincott
712 Williams & Wilkins, pp.1339–1355.
- 713 52. Sattar, S.A., M. Abehe, A.J. Bueti, H. Jampani, J. Newman, and S. Hua, 2000.
714 Activity of an alcohol-based hand gel against human adeno-, rhino-, and

715 rotaviruses using the finger pad method. *Infect. Cont. Hosp. Epidemiol.* 21:516-
 716 519.

717 53. Scallan E, RM Hoekstra, FJ Angulo, RV Tauxe, MA Widdowson, Roy SL, Jones
 718 JL, and PM Griffin, 2011. Foodborne illness acquired in the United States –
 719 major pathogens. *Emerg Infect. Dis.* 17: 7-17 Available at:
 720 http://wwwnc.cdc.gov/eid/article/17/1/P1-1101_article.htm. Accessed on 3
 721 February 2016.

722 54. Shintre, M.S., T.A. Gaonkar, and S.M. Modak, 2006. Efficacy of an alcohol-
 723 based health care hand rub containing synergistic combination of farnesol and
 724 benzethonium chloride. *Int. J. Hyg. Environ. Health* 209:477-487.

725 55. Steinmann, J., D. Paulmann, B. Becker, B. Bischoff, E. Steinmann, and J.
 726 Steinmann, 2012. Comparison of virucidal activity of alcohol-based hand
 727 sanitizers versus antimicrobial hand soaps *in vitro* and *in vivo*. *J. Hosp. Infect.*
 728 82:277-280.

729 56. Todd E.C.D, J.D. Greig, C.A. Barleson, and B.S. Micheals, 2007. Outbreaks
 730 where food workers have been implicated in the spread of foodborne disease.
 731 Part 2. Description of outbreaks by size, severity, and setting. *J. Food Prot.*
 732 70(8): 1975-1993.

733 57. Todd E.C.D, J.D. Greig, C.A. Barleson, and B.S. Micheals, 2007. Outbreaks
 734 where food workers have been implicated in the spread of foodborne disease.
 735 Part 3. Factors contributing to outbreaks and description of outbreaks. *J. Food*
 736 *Prot.* 70(9): 2199-2217.

737 58. Todd E.C.D, J.D. Greig, C.A. Barleson, and B.S. Micheals, 2008. Outbreaks
 738 where food workers have been implicated in the spread of foodborne disease.
 739 Part 4. Infective dose and pathogen carriage. *J. Food Prot.* 70(11): 2339-2373.

740 59. Todd E.C.D, J.D. Greig, C.A. Barleson, and B.S. Micheals, 2009. Outbreaks
741 where food workers have been implicated in the spread of foodborne disease.
742 Part 6. Transmission of pathogens in food processing and preparation
743 environment. *J. Food Prot.* 70(1): 202-219.

744 60. World Health Organization, 2009. WHO guidelines on hand hygiene and health-
745 care. First global patient safety challenge clean care is safer care. Section 11.2 :
746 Plain (non-antimicrobial soap). Geneva, World Health Organization; 2009. ISBN-
747 13: 978-92-4-159790-6.

748 61. Wongworawat, M.D., G. Sidney, and M.D. Jones, 2007. Influence of rings on the
749 efficacy of hand sanitization and residual bacterial contamination. *Infect. Cont.*
750 *Hosp. Epidemiol.* 28(3): 351-353.

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755 Table 1. Number of scientific publications matching search terms retrieved from
 756 three different electronic databases.

Search term	Web of Science	Scopus	PubMed	Total
"Efficacy of hand washing"	351	690	456	1497
"Efficacy of hand sanitizers"	63	62	23	148
"Evaluation of hand sanitisers"	28	30	2	60
"Effect of hand hygiene products"	166	160	77	403
Number of unique articles				
retrieved	21	10	7	38
Number of articles excluded*	4	4	3	10
Number of articles reviewed	17	6	5	28

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758 *Three of the excluded papers were review articles, other seven did not meet inclusion criteria.

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765 Table 2. Summary of results regarding efficacy of hand sanitisers presented in the scientific papers included in this systematic
766 review.

References	Microorganism	Test method	Hand hygiene products and disinfectants	Reduction observed
Czerwinski & Cozean (9)	FCV	Finger pad	Novel alcohol-based antiseptic containing BZT	3.49 Log ₁₀
			Hand sanitizer (62% ethanol)	0.14 Log ₁₀
			Hand washing with antibacterial soap	0.67 Log ₁₀
			Water rinse	1.09 Log ₁₀
	<i>E. coli</i>	Pig skin method 2 min post application 1h post application 4h post application	Novel alcohol-based antiseptic containing BZT	1.65 Log ₁₀
				1.34 Log ₁₀
				1.15 Log ₁₀
	<i>St. aureus</i>	2 min post application 1h post application 4h post application	Novel alcohol-based antiseptic containing BZT	1.87 Log ₁₀
				2.14 Log ₁₀
				1.62 Log ₁₀
Edmonds et al. (15)		Moderate food soil load	Non-antimicrobial hand wash	3.10±0.61 Log ₁₀
			PCMX hand wash	3.56±0.64 Log ₁₀
			WS (non-antimicrobial hand wash + 62% EtOH foam)	3.81±0.89 Log ₁₀
			WS (PCMX hand wash+62% EtOH foam)	4.16±0.91 Log ₁₀
			WS (non-antimicrobial hand wash +70% EtOH AF gel)	5.13±0.71 Log ₁₀
			WS (PCMX hand wash +70% EtOH AF gel)	5.22±0.60 Log ₁₀
		Heavy food soil load	WS (non-antimicrobial hand wash + 62% EtOH foam)	4.11±0.48 Log ₁₀
			WS (Triclosan hand wash+62% EtOH foam)	3.97±0.45 Log ₁₀
			WS (PCMX and wash +70% EtOH AF gel)	4.60±0.52 Log ₁₀
			WS (Triclosan hand wash +70% EtOH AF gel)	4.51±0.43 Log ₁₀
		Organic soil load (5% fetal bovine serum)	Non-antimicrobial hand wash	1.79±0.29 Log ₁₀
			ABHRs (70% EtOH AF gel)	2.60±0.41 Log ₁₀
			WS (non-antimicrobial hand wash + 70% EtOH AF gel)	3.19±0.31 Log ₁₀
	MNV		STW (70% EtOH AF gel)	4.04±0.33 Log ₁₀

Table 2 continued				
Gehrke et al. (29)	FCV	Suspension 30 s exposure	EtOH 50%	2.19 Log ₁₀
			EtOH 70%	3.55 Log ₁₀
			EtOH 80%	2.19 Log ₁₀
			1-Propanol 50%	≥ 4.13 Log ₁₀
			1-Propanol 70%	≥ 4.06 Log ₁₀
			1-Propanol 80%	1.90 Log ₁₀
			1-Propanol 50%	2.31 Log ₁₀
			1-Propanol 70%	2.35 Log ₁₀
			1-Propanol 80%	1.35 Log ₁₀
		Finger tips	EtOH 70%	3.78±0.83 Log ₁₀
			EtOH 90%	2.84±0.64 Log ₁₀
			1-Propanol 70%	3.58±0.92 Log ₁₀
			1-Propanol 90%	1.38±0.33 Log ₁₀
			2-Propanol 70%	2.15±0.50 Log ₁₀
			2-Propanol 90%	0.76±0.19 Log ₁₀
			Water	1.23±0.44 Log ₁₀
Kampf et al. (36)	FCV	Fingerpad	Reference alcohols (70% Ethanol)	1.45±0.41 Log ₁₀
		Organic soil	Sterillium Virugard (95% Ethanol)	2.17±1.06 Log ₁₀
		5% fetal bovine serum	Sterillium Rub (80% Ethanol)	1.25±0.28 Log ₁₀
			Desderman N (75.1% Ethanol)	1.07±0.61 Log ₁₀
Lages et al. (38)	FCV	Finger tips 30 s and 2 min contact periods	ABHRs (99.5% Ethanol)	1.00 (30s) - 1.30 (2 min) Log ₁₀
			Hand sanitizer (62% Ethanol)	0.50 (30s) - 0.55 (2 min) Log ₁₀
			Antiseptic (91% Isopropanol)	0.00 (30s) - 0.43 (2 min) Log ₁₀
			Antiseptic (70% Isopropanol)	0.67 (30s) - 0.55 (2 min) Log ₁₀
			Antiseptic (3% Hydrogen peroxide)	0.09 (30s) - 0.47 (2 min) Log ₁₀
			Antiseptic (0.13% Benzalkonium chloride + 2% lidocaine hydrochloride)	0.00 (30s) - 0.22 (2 min) Log ₁₀
			Antiseptic (10% Povidone-iodine)	2.67 (30s) - 2.39 (2 min) Log ₁₀
			Antimicrobial soap (0.60% Triclosan)	0.25 (30s) - 0.50 (2 min) Log ₁₀
			Antimicrobial soap (0.115% Triclosan)	0.42 (30s) - 0.17 (2 min) Log ₁₀
			Water	0.33 (30s) - 0.42 (2 min) Log ₁₀
Lin et al. (40)	FCV	Fingertips (Artificial feces)	Tap water	1.22±0.86 ⁽¹⁾ Log ₁₀
				1.97±0.68 ⁽²⁾ Log ₁₀
			Soap	1.89±0.31 ⁽¹⁾ Log ₁₀
				1.82±0.46 ⁽²⁾ Log ₁₀

Table 2 continued				
<i>E. coli</i>		Fingertips Heavy food soil load	Antibacterial soap (Triclosan)	1.65±0.19 ⁽¹⁾ Log ₁₀
				2.26±0.42 ⁽²⁾ Log ₁₀
			Hand sanitizers (62% Ethanol)	0.43±0.47 ⁽¹⁾ Log ₁₀
				0.86±0.55 ⁽²⁾ Log ₁₀
			Soap plus sanitizer	1.85±0.69 Log ₁₀ ⁽¹⁾
				2.13±0.93 Log ₁₀ ⁽²⁾
			Soap plus nail brush	0.41±0.49 Log ₁₀ ⁽¹⁾
				2.54±0.57 Log ₁₀ ⁽²⁾
			Tap water	1.29±0.53 Log ₁₀ ⁽¹⁾
				1.18±0.14 Log ₁₀ ⁽²⁾
			Soap	1.09±0.51 Log ₁₀ ⁽¹⁾
				1.18±0.24 Log ₁₀ ⁽²⁾
			Antibacterial soap (Triclosan)	1.26±0.47 Log ₁₀ ⁽¹⁾
				1.45±0.59 Log ₁₀ ⁽²⁾
			Hand sanitizer (62% Ethanol)	1.16±0.63 Log ₁₀ ⁽¹⁾
				1.31±0.68 Log ₁₀ ⁽²⁾
Liu et al. 2010 (41)	HuNoV	Fingerpad	Soap plus sanitizer	1.59±0.45 Log ₁₀ ⁽¹⁾
				1.85±0.84 Log ₁₀ ⁽²⁾
			Soap plus nail brush	2.54±0.54 Log ₁₀ ⁽¹⁾
				3.07±1.18 Log ₁₀ ⁽²⁾
			Hand sanitizer (62% Ethanol)	0.27±0.12 Log ₁₀ ⁽³⁾
				0.34±0.22 Log ₁₀ ⁽⁴⁾
			Antibacterial soap (0.5% Triclosan)	0.67±0.47 Log ₁₀ ⁽³⁾
				1.10±0.49 Log ₁₀ ⁽⁴⁾
Liu et al (42)	HuNoV	Fingerpad	Water rinse	0.58±0.37 Log ₁₀ ⁽³⁾
				1.38±0.49 Log ₁₀ ⁽⁴⁾
			Hand sanitizer (VF481 - 70% Ethanol)	3.74±0.85 Log ₁₀
			Hand sanitizer (VF447 - 70% Ethanol)	2.04±0.78 Log ₁₀
			Hand sanitizer (Endure 300 - 70% Ethanol)	1.49±0.62 Log ₁₀
			Hand sanitizer (Sterillium Virugard - 95% Ethanol)	0.10±0.17 Log ₁₀
			Hand sanitizer (Germstar Noro - 63% Ethanol)	0.11±0.22 Log ₁₀
			Hand sanitizer (Anios Gel 85 NPC - 85% Ethanol)	1.27±0.22 Log ₁₀
Park et al. (46)	HuNoV	Suspension (1 min exposure)	Hand sanitizer (79% Ethanol - pH 7.1)	0.1±0.2 Log ₁₀ ⁽⁵⁾
			Hand sanitizer (72% Ethanol - pH 4.1)	0.0±0.2 Log ₁₀ ⁽⁵⁾
			Hand sanitizer (72% Ethanol - pH 2.9)	0.1±0.1 Log ₁₀ ⁽⁵⁾
			Hand sanitizer (67% Ethanol - pH 7.4)	0.2±0.2 Log ₁₀ ⁽⁵⁾

Table 2 continued				
MNV			Hand sanitizer (0.1% Triclosan - pH 3.0)	0.0±0.3 Log ₁₀ ⁽⁵⁾
			Hand sanitizer (0.2% Triclosan - pH 3.0)	0.0±0.1 Log ₁₀ ⁽⁵⁾
			Hand sanitizer (4% Chlorhexidine - pH 5.4)	0.0±0.1 Log ₁₀ ⁽⁵⁾
			Hand sanitizer (79% Ethanol - pH 7.1)	3.01±0.05 Log ₁₀ ⁽⁵⁾
				>3.6 Log ₁₀ ⁽⁶⁾
			Hand sanitizer (72% Ethanol - pH 4.1)	0.0±0.5 Log ₁₀ ⁽⁵⁾
				>3.6 Log ₁₀ ⁽⁶⁾
			Hand sanitizer (72% Ethanol - pH 2.9)	0.1±0.5 Log ₁₀ ⁽⁵⁾
				>2.6 Log ₁₀ ⁽⁶⁾
			Hand sanitizer (67% Ethanol - pH 7.4)	1.9±0.4 Log ₁₀ ⁽⁵⁾
				2.0±0.2 Log ₁₀ ⁽⁶⁾
			Hand sanitizer (0.1% Triclosan - pH 3.0)	0.4±0.3 Log ₁₀ ⁽⁵⁾
				1.1±0.1 Log ₁₀ ⁽⁶⁾
			Hand sanitizer (0.2% Triclosan - pH 3.0)	0.0±0.2 Log ₁₀ ⁽⁵⁾
FCV				0.2±0.1 Log ₁₀ ⁽⁶⁾
			Hand sanitizer (4% Chlorhexidine - pH 5.4)	0.0±0.1 Log ₁₀ ⁽⁵⁾
				0.0±0.3 Log ₁₀ ⁽⁶⁾
			Hand sanitizer (79% Ethanol - pH 7.1)	0.8±0.7 Log ₁₀ ⁽⁵⁾
				0.0±0.2 Log ₁₀ ⁽⁶⁾
			Hand sanitizer (72% Ethanol - pH 4.1)	0.7±0.9 Log ₁₀ ⁽⁵⁾
				0.0±0.2 Log ₁₀ ⁽⁶⁾
			Hand sanitizer (72% Ethanol - pH 2.9)	0.9±0.8 Log ₁₀ ⁽⁵⁾
				>3.4 Log ₁₀ ⁽⁶⁾
			Hand sanitizer (67% Ethanol - pH 7.4)	0.8±0.4 Log ₁₀ ⁽⁵⁾
				0.4±0.2 Log ₁₀ ⁽⁶⁾
			Hand sanitizer (0.1% Triclosan - pH 3.0)	0.0±0.7 Log ₁₀ ⁽⁵⁾
				>3.4 Log ₁₀ ⁽⁶⁾
			Hand sanitizer (0.2% Triclosan - pH 3.0)	0.2±0.2 Log ₁₀ ⁽⁵⁾
				>3.4 Log ₁₀ ⁽⁶⁾
Steinmann et al. (55) FCV	Suspension (30s exposure)		Hand sanitizer (45% Ethanol)	> 5 Log ₁₀
			Hand sanitizer (55% Ethanol)	> 5 Log ₁₀
			Hand sanitizer (90% Ethanol)	< 1 Log ₁₀

Table 2 continued				
	MNV	Suspension (30s exposure)	Antimicrobial liquid soap (1% Triclosan)	< 1 Log ₁₀
			Antimicrobial liquid soap (4% Chlorexidine)	< 1 Log ₁₀
			Antimicrobial liquid soap (0.75-0.81% available iodine)	3 Log ₁₀
			Hand sanitizer (45% Ethanol)	5 Log ₁₀
			Hand sanitizer (55% Ethanol)	> 5 Log ₁₀
			Hand sanitizer (90% Ethanol)	> 4 Log ₁₀
	MNV	Modified fingerpad	Antimicrobial liquid soap (1% Triclosan)	< 1 Log ₁₀
			Antimicrobial liquid soap (4% Chlorexidine)	< 1 Log ₁₀
			Antimicrobial liquid soap (0.75-0.81% available iodine)	> 2 Log ₁₀
			Hand sanitizer (45% Ethanol)	4.25 Log ₁₀
			Hand sanitizer (55% Ethanol)	3.94 Log ₁₀
			Hand sanitizer (90% Ethanol)	3.91 Log ₁₀
Mbithi et al. 1993 (43)	HAV	Fingerpad	Antimicrobial liquid soap (1% Triclosan)	3.42 Log ₁₀
			Antimicrobial liquid soap (4% Chlorexidine)	0.96 Log ₁₀
			Antimicrobial liquid soap (0.75-0.81% available iodine)	4.62 Log ₁₀
			Water	3 Log ₁₀
			Alcare (62% emolliented ethanol foam)	89.27 ± 4.38%
			Aquaress (nonantimicrobial soap)	77.96 ± 7.17%
			Bacti-Stat soap (0.1% Chlorhexidine gluconate, 0.50% Didecyl dimethyl ammonium chloride, 5% Isopropanol)	92.04 ± 4.02%
			Bioprep hand soap	83.35 ± 2.76%
			Dettol (4.8% 4-Chloro-3,5-xyleneol, 9.4% Isopropanol)	88.63 ± 5.38%
			70% Ethanol	87.40 ± 4.59%
			Savlon (1.5% Chlorhexidine gluconate, 15% Cetrimide)	90.91 ± 5.08%
			Scrub Stat IV (4% Chlorhexidine gluconate, 4% Isopropanol)	89.57 ± 6.70%
			Septisol (0.75% Hexachlorophene)	88.60 ± 5.36%
			Tap water	79.74 ± 4.80%
			Triclosan hand soap (Triclosan 0.5%)	91.29 ± 4.47%

Table 2 continued				
		Whole hand	Alcare (62% emolliented ethanol foam)	86.17 ± 4.28%
			Aquaress (nonantimicrobial soap)	91.39 ± 2.65%
			Bacti-Stat soap (0.1% Chlorhexidine gluconate, 0.50% Didecyl dimethyl ammonium chloride, 5% Isopropanol)	94.56 ± 5.75%
			Bioprep hand soap	81.44 ± 1.59%
			Dettol (4.8% 4-Chloro-3,5-xyleneol, 9.4% Isopropanol)	90.67 ± 2.08%
			70% Ethanol	86.92 ± 1.63%
			Savlon (1.5% Chlorhexidine gluconate, 15% Cetrimide)	86.53 ± 3.44%
			Scrub Stat IV (4% Chlorhexidine gluconate, 4% Isopropanol)	81.15 ± 1.15%
			Septisol (0.75% Hexachlorophene)	89.20 ± 0.81%
			Tap water	81.57 ± 4.55%
			Triclosan hand soap (Triclosan 0.5%)	88.98 ± 1.73%
Fendler & Groziak (20)	HAV	Suspension (30s exposure)	Purell Instant Hand Sanitizer (62% Ethanol+emollients)	1.25 Log ₁₀
McCarthy (44)	<i>L. monocytogenes</i>	Glove immersion (30s) PBS (PBS) and Crab cooking water (CCW)	50 PPM Chloride (50ppm Sodium hypochlorite)	5 ^(PBS) - 3 ^(CCW) Log ₁₀
			100 PPM Chloride (50ppm Sodium hypochlorite)	5 ^(PBS) - 3 ^(CCW) Log ₁₀
			Zep-I-dine™ (25 iodine)	3 ^(PBS) - 3 ^(CCW) Log ₁₀
			Zepamine A™ (195 ppm active quaternaries)	5 ^(PBS) - > 4 ^(CCW) Log ₁₀
			Zep™ hand sanitizer (62% Ethanol)	4 ^(PBS) - 3 ^(CCW) Log ₁₀
			Ultra Kleen (Peroxide-based powder 56g/3.8 L of water)	5 ^(PBS) - 5 ^(CCW) Log ₁₀
Edmonds et al (14)	<i>E. coli</i>	Hand test		
		Moderate food soil load	Non-antimicrobial hand wash	2.86 Log ₁₀
			STW (62% Ethanol gel)	2.84 Log ₁₀
			STW (62% Ethanol foam)	3.84 Log ₁₀
			70% AF foam	4.44 Log ₁₀
			STW (70% AF foam)	4.61 Log ₁₀
		Heavy food soil load	Non-antimicrobial hand wash	2.65 Log ₁₀
			STW (62% Ethanol gel)	2.69 Log ₁₀
			STW (62% Ethanol foam)	2.87 Log ₁₀
			70% AF foam	2.99 Log ₁₀
			STW (70% AF foam)	3.92 Log ₁₀

Table 2 continued				
Kampf et al. (37)	<i>E. coli</i>	Hand test	Purell Instant Hand Sanitizer (62% Ethanol) Alcare plus (62% Ethanol) Water	3.05 ± 0.45 Log ₁₀ 3.58 ± 0.71 Log ₁₀ 2.39 ± 0.57 Log ₁₀
Czerwinski et al. (10)	<i>E. coli</i>	Suspension (15 s)	Hand sanitizer (Zylast Antiseptic, 76% Ethanol) Water-based antiseptic lotion (Zylast-Lotion, 0.2% BZT)	>6.14 Log ₁₀ (99.9%) >6.14 Log ₁₀ (99.9%)
	<i>St. aureus</i>	Suspension (15s)	Hand sanitizer (Zylast Antiseptic, 76% Ethanol) Water-based antiseptic lotion (Zylast- 0.2% BZT)	>6.14 Log ₁₀ (99.9%) 4.09 Log ₁₀ (99.9%)
Courtenay et al. (8)	<i>E. coli</i>	Hand test Heavy soil load Ground beef	Cool water Warm water Hand washing with plain soap	94.96% ⁽⁷⁾ 40.1% ⁽⁸⁾ 99.78% ⁽⁷⁾ 79.7% ⁽⁸⁾ 99.98% ⁽⁷⁾ 91.3% ⁽⁸⁾
		Hand test (not soiled hands)	Hand sanitizer B (62% Ethanol+skin conditioner) Hand sanitizer c (62% Ethanol+skin conditioner) Hand sanitizer P (62% Ethanol+skin conditioner) Hand sanitizer S (62% Ethanol+skin conditioner)	94.44% ⁽⁷⁾ 96.33% ⁽⁷⁾ 96.07% ⁽⁷⁾ 90.40% ⁽⁷⁾
Fishler et al. (22)	<i>E.coli</i>	Hand test	Hand washing with plain soap Antimicrobial soap (0.46% Triclosan)	<2 Log ₁₀ >3 Log ₁₀
Gaonkar et al. (28)	<i>E. coli</i>	Suspension (15 s exposure)	Octoxy hand rub	7 Log ₁₀
		Pig skin method (15 min post application)	Hand sanitizer (60% EtOH +Phenoxyethanol+BZK) Hand sanitizer Avagards (61% EtOH +CHG) Octoxy hand rub	Residual 4.96 Log ₁₀ Residual 5.04 Log ₁₀ Residual 0 Log ₁₀
	<i>St. aureus</i>	Suspension (15 s exposure)	Octoxy hand rub	7 Log ₁₀
		Pig skin model 15 min post application	Hand sanitizer (60%EtOH +phenoxyethanol+BZK) Hand sanitizer Avagards (61% EtOH+CHG) Octoxy hand rub	Residual 5.11 Log ₁₀ Residual 5.68 Log ₁₀ Residual 0 Log ₁₀

Table 2 continued				
Paulson et al. (47)	<i>E.coli</i>	Hand test	Hand washing with plain soap	2.12 Log ₁₀
			Antibacterial soap (PCMX)	1.9 Log ₁₀
			Purell Hand sanitizer gel (62% Ethanol)	2.24 Log ₁₀
			WS (antibacterial soap+hand sanitizer)	3.28 Log ₁₀
Pickering et al. (48)	<i>E.coli</i>	Hand test:		
		Clean hand	ABHS	2.33 Log ₁₀
		Dirt-covered hand	ABHS	2.32 Log ₁₀
		Oil-coated hand	ABHS	2.13 Log ₁₀
Shintre et al. (54)	<i>E.coli</i>	Suspension	ZBF hand rub (60% Ethanol+Farnesol+Benzethonium chloride)	>7 Log ₁₀
	<i>E.coli</i>	Pig skin model (20 m post application)	ZBF hand rub (60% Ethanol+Farnesol+Benzethonium chloride)	Residual 3.26 Log ₁₀
			Avagard™	Residual 4.70 Log ₁₀
			Prevacare™	Residual 5.65 Log ₁₀
			Triseptins	Residual 5.12 Log ₁₀
			Alcohol gel base	Residual 5.60 Log ₁₀
	<i>St. aureus</i>	Suspension	ZBF hand rub (Ethanol+Farnesol+Benzethonium chloride)	>7 Log ₁₀
		Pig skin model (20 min post application)	ZBF hand rub (Ethanol+Farnesol+Benzethonium chloride)	Residual 1.89 Log ₁₀
			Avagard™	Residual 4.94 Log ₁₀
			Prevacare™	Residual 5.16 Log ₁₀
			Triseptins	Residual 5.51 Log ₁₀
			Alcohol gel base	Residual 5.37 Log ₁₀
Edmonds et al. (16)	<i>St. aureus</i>	Suspension (15 s exposure)	Purell advanced hand sanitizer - 70% Ethanol gel	≥5.8 Log ₁₀
			Purell advanced hand sanitizer - 70% Ethanol foam	≥4.2 Log ₁₀
			Ethanol 70%	≥4.2 Log ₁₀
		Hand test After 1 ^(1A) and 10 applications ^(10A)	Purell advanced hand sanitizer - 70% Ethanol gel	3.58 ^(1A) Log ₁₀ - 3.50 ^(10A) Log ₁₀
			Purell advanced hand sanitizer - 70% Ethanol foam	3.55 ^(1A) Log ₁₀ - 3.48 ^(10A) Log ₁₀
			Sterillium comfort gel (90% ethanol gel)	3.12 ^(1A) Log ₁₀ - 1.80 ^(10A) Log ₁₀
			WHO recommended hand rub (80% Ethanol)	3.07 ^(1A) Log ₁₀ - 2.39 ^(10A) Log ₁₀
			WHO recommended hand rub (75% Ethanol)	3.12 ^(1A) Log ₁₀ - 2.03 ^(10A) Log ₁₀

Table 2 continued				
			Purell advanced hand sanitizer - 70% Ethanol gel	3.35 ^(1A) Log ₁₀ - 4.09 ^(10A) Log ₁₀
			Purell advanced hand sanitizer - 70% Ethanol foam	3.48 ^(1A) Log ₁₀ - 4.41 ^(10A) Log ₁₀
			Endure 300 antimicrobial rinse - 62% Ethanol	2.99 ^(1A) Log ₁₀ - 1.97 ^(10A) Log ₁₀
			Avagard foam instant hand antiseptic (70% Ethanol)	2.83 ^(1A) Log ₁₀ - 1.94 ^(10A) Log ₁₀
			Avagard D (68% Ethanol)	2.48 ^(1A) Log ₁₀ - 1.31 ^(10A) Log ₁₀
			Alcare OR Foamed antiseptic hand rub (62% Ethanol)	2.86 ^(1A) Log ₁₀ - 2.71 ^(10A) Log ₁₀
			Rio gel antiseptico (70% Ethanol)	2.88 ^(1A) Log ₁₀ - 2.47 ^(10A) Log ₁₀
			Cutan Alcohol foam antiseptic hand rub (60%Ethanol)	3.26 ^(1A) Log ₁₀ - 2.54 ^(10A) Log ₁₀
Kaiser et al. (35)	<i>St. aureus</i>	Pig skin model	CHG wash only	4.22 Log ₁₀
			CHG wash + 60% alcohol gel product and 0.25% Hydroxypropyl cellulose	4.12 Log ₁₀
			CHG wash + 0.25% Carbomer in alcohol solution	1.07 Log ₁₀
			CHG wash + 0.25% C10-30 Alkyl acrylate crosspolymer in alcohol solution	0.44 Log ₁₀
			CHG wash + unthickened alcohol solution	4.11 Log ₁₀
			CHG wash + Carbomer containing marketed Product A	0.54 Log ₁₀
			CHG wash + Carbomer containing marketed Product B	0.56 Log ₁₀
			CHG wash + Hydroxypropyl cellulose containing marketed Product C	4.26 Log ₁₀
Fendler et al. (21)	<i>Escherichia coli</i> <i>Escherichia coli</i> (O157;H7) <i>L. monocytogenes</i> <i>St. aureus</i> - methicillin-resistant strain. <i>St. aureus</i> - vancomycin-tolerant-methicillin-resistant <i>Salmonella</i> Enteritidis <i>Salmonella</i> Typhimurium Hepatitis A virus	Suspension (30 s exposure)	Purell Instant Hand Sanitizer (62% Ethanol+emollients)	>5 Log ₁₀
				>5 Log ₁₀
				>5 Log ₁₀
				>5 Log ₁₀
				>5 Log ₁₀
				>5 Log ₁₀
				>5 Log ₁₀
				1.75 Log ₁₀
Charbonneau et al (7)	Natural food flora	Hand test Heavy soil load	Hand wash with non-medicated soap	W&S > WS > ABHSs
			Hand sanitizer (70% Ethanol)	ABHSs < W&S < WS
			WS (non-antimicrobial hand wash + 70% ETOH foam)	WS < W&S > ABHSs
Wongworawat et al. (61)	Natural flora	Hand test	Povidone-iodine scrub	Residual 2.5 CFU ^(WR) - 7.5 CFU ^(R)
			Water-aided alcohol wash	Residual 0.5 CFU ^(WR) - 1.0 CFU ^(R)
			Water-less alcohol-chlorexidine lotion	Residual 0.0 CFU ^(WR) - 0.0 CFU ^(R)

767 *Hand product: BZT, Benzethonium chloride; W & S, water and soap; ABHRs, alcohol-based hand rubs; WS, Wash-sanitise; CHG,
768 Chlorhexidine gluconate; STW, Sani-twice; W, PCMX, Para-chloro-meta-xyleneol.

769 FCV, feline calicivirus; MNV, murine norovirus; HuNoV, human norovirus; HAV, Hepatitis A virus

770 ⁽¹⁾ Artificial fingernails

771 ⁽²⁾ Natural fingernails

772 ⁽³⁾ Standard American Society for Testing and Materials (ASTM) finger pad method with rubbing (ASTM) finger pad method

773 ⁽⁴⁾ Modified American Society for Testing and Materials (ASTM) finger pad method (with rubbing)

774 ⁽⁵⁾ Viral reduction estimated through RT-qPCR

775 ⁽⁶⁾ Viral reduction estimated through Plaque assay

776 ⁽⁷⁾ Bare hands

777 ⁽⁸⁾ Gloves

778 ^(R) = Hands with ring(s)

779 ^(WR) = Hands without rings

780