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E. coli from dishcloths as an indicator of hygienic status in households

V. Keshav, C. A. Kruger, A. Mathee, N. Naicker, A. Swart and T. G. Barnard

ABSTRACT

E. coli is routinely used as an indicator of fecal pollution, although some strains are capable of causing diarrhea. *E. coli* was used as a model organism for this study to assess the possibility that dishcloths used in households could contribute to the occurrence of diarrhea. Dishcloths ($n = 424$) were collected from five suburbs in Johannesburg (South Africa) as part of a larger Health, Environment & Development (HEAD) study. Results for the total coliforms indicated that on average 81% of the samples analyzed had total coliform counts of more than 1,000 cfu/100 ml per 25 cm^2 cloth. The *E. coli* results indicated that 40% of the samples had culturable *E. coli* present with 17% of the samples showing the presence of $>$1,000 cfu/100 ml per 25 cm^2 cloth. Except for the samples from Bertrams, all the pathogenic *E. coli* genes could be detected in various combinations in the different samples. Since all the diarrheagenic *E. coli* strains detected can be accepted as culturable due to the enrichment step, there is a clear danger of contamination of food and surfaces exposed to the contaminated dishcloths. The results indicated that there is a need for public education regarding hygiene in the households, especially if the same dishcloth is used for various tasks.

Key words | contaminated dishcloths, fecal contamination, home-based hygiene

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INTRODUCTION

According to the United Nations (2013) the Millennium Development Goal (MDG) Goal 7, focusing on sanitation, hygiene and water quality, has achieved a 13% increase (1990–2010) in providing access to improved drinking water sources globally. However, over 40% of people in sub-Saharan Africa still do not have access to improved water sources and 2.5 billion (10^9) people lack access to adequate sanitary facilities. Despite the progressive efforts as outlined in the MDGs to improve the lives of 100 million people living in slum dwellings by 2015, the hindrance often encountered is due to negligence of hygienic practices within the society. Infectious diseases are frequently reported, due to deviations from hygiene practices executed in households which differ amongst individuals, to communities, states and countries. Factors such as age, health and immunity of individuals may also affect public health. Moreover, many domestic households contribute to a decrease in water quality, sanitation and hygiene practices leading to disease outbreaks (Curtis *et al.* 2003; Bloomfield *et al.* 2007; Aiello *et al.* 2008; Pickering *et al.* 2011; Stauber *et al.* 2013).

Soares *et al.* (2012) stated that up to 87% of reported outbreaks originated either from improperly prepared or consumed food in homes. Furthermore bacterial cells variably adhere to different materials such as wood, plastic, glass or stainless steel equipment or surfaces used in domestic kitchens and thus, further contribute in the spread of microorganisms (Ojima *et al.* 2002; Moore & Griffith 2006; Rossi *et al.* 2013). In addition it was stated that bacterial strains were more prevalent on wet substances such as drain taps, dish-washing sponges, counter towels, sinks and bathroom sponges. An essential study carried out by Rayner *et al.* (2004) reported the prevalence of biofilms on various surfaces in households. Biofilms are habitually resistant to general cleaning protocols used at homes and hence these protocols may be insufficient to remove such contamination. Such findings are building evidence of the

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survival of microorganisms in domestic kitchens and their ability to act as fomites to cross contaminate other areas. Table 1 summarizes the frequently reported sources considered hazardous in spreading infections.

Of the many bases of potential carriers identified, kitchen dishcloths and sponges were reported to have the highest bacterial count as they mostly remain wet and serve both as a reservoir and disseminator of pathogens (Kagan *et al.* 2002; Aiello *et al.* 2008). In many African homes, dishcloths are used for multiple purposes such as cleaning dishes, wiping various surfaces, walls and floors, and consequently potentially transferring pathogens throughout the household. Sharma *et al.* (2009) reported that dishcloths transferred *Escherichia coli* O157:H7 (*E. coli*) to surfaces more frequently than *Salmonella* species. Additionally Kagan *et al.* (2002) stated that *E. coli* cells may survive in temperatures higher than 50 °C. This is of concern as water used to wash food products, kitchen surfaces and utensils is usually below 50 °C and hence contributes in the spread of pathogenic bacteria. Pathogenic *E. coli*, namely enterotoxigenic *E. coli* (ETEC), enterohemorrhagic *E. coli* (EHEC), enteroaggregative *E. coli* (EAEC), enteroinvasive *E. coli* (EIEC) and enteropathogenic *E. coli* (EPEC), targets the gastrointestinal tract of humans and is responsible for causing infections leading to diarrhea and dysentery (Donnenberg 2002).

In an attempt to understand the occurrence of microorganisms in households, *E. coli* was chosen as an indicator organism to evaluate the hygienic status of dishcloths and sponges. The occurrence of *E. coli* is an indication of fecal contamination and can also indicate the presence of other pathogens such as *Shigella*, *Salmonella*, *Aeromonas*, *Campylobacter jejuni*, *Yersinia* and *Campylobacter coli* associated with fecal pollution (Liu *et al.* 2011), further

Table 1 | Identified potential pathogenic carriers and transmitters found within households

Source	Contact	Identified transmission pathway to humans	Risk Involved	References
Dishcloths	Indirect	Raw food, water, hands, airborne, skin scales	Wet or moist conditions are ideal for survival of bacterial cells up to several hours	Kagan *et al.* (2002), Mattick *et al.* (2003a, 2003b), Bloomfield *et al.* (2007), Rossi *et al.* (2013)
Food	Direct/indirect	Uncooked food, water and hands	Serves as a nutritional source for bacteria	Jong *et al.* (2008), Pickering *et al.* (2011), Beltran *et al.* (2013)
Floors, furniture and walls, surfaces	Indirect	Wash-cloths, hands, airborne, skin scales	Bacterial cells are known to survive in dust	Rayner *et al.* (2004), Bloomfield *et al.* (2007), Sinclair & Gerba (2010), Chang *et al.* (2013)
Fomite	Indirect	Hands, airborne	Carrier for bacterial cells	Sinclair & Gerba (2010)
Personal hygiene	Direct	Unwashed hands	Lack of knowledge/practice	Curtis *et al.* (2003)
Toys	Indirect	Hands, mouth	Carrier for bacterial cells and direct mouth contact with kids	Stauber *et al.* (2013)
Toilets, baths, sinks	Indirect	Skin scales, airborne, hands	Bacterial cells adhere to surfaces and can be viable up to several hours	Kagan *et al.* (2002), Ojima *et al.* (2002), Sinclair & Gerba (2010)
Utensils and equipment	Indirect	Hands, food, wash-cloths	Carrier for bacterial cells	Soares *et al.* (2012), Jensen *et al.* (2013)
Water	Direct/indirect	Consumption, uncooked food, cross-contaminated dishcloths, utensils and surfaces	Temperature of water used for various household chores is generally below 50 °C	Jong *et al.* (2008), Mattick *et al.* (2003a, 2003b)
Waste disposal	Indirect	Hands, airborne	Serves as a nutritional source for bacteria	Scott (1999)

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increasing the risk for diarrhea and other related infections. Thus dishcloth testing could be the link to measure unsanitary hygienic practices at homes traced with *E. coli* pathogens isolated from other various contaminated water sources.

METHODOLOGY

Growth and maintenance of bacterial strains

A commensal *E. coli* strain was isolated and confirmed using the API 20E strip. This strain was cultured using the Plate Count Agar (PCA) (Oxoid) method and incubated at 37 °C for 16 hours under aerobic conditions. This was used as a positive control for the Colilert® Quanti-Tray®/2000 method. *Klebsiella pneumoniae* [KLEPN 01, National Health Laboratory Service (NHLS)], and *Pseudomonas aeruginosa* (PSEAE 01, NHLS) were cultured using the Plate Count Agar (PCA) (Oxoid) method and incubated at 37 °C for 16 hours under aerobic conditions. This was used as a negative control for the Colilert® Quanti-Tray®/2000 method.

Sample collection

To test for the presence of *E. coli*, dishcloths ($n = 424$) were collected from participating households in Hillbrow ($n = 50$), Bertrams ($n = 25$), Riverlea Extension 1 ($n = 101$), Braamfischerville ($n = 105$) and Hospital Hill ($n = 143$) that formed part of a larger Health, Education & Development (HEAD) study in Johannesburg, South Africa. Participants were asked to place the dishcloths in sterile bags in exchange for new dishcloths. Before sample analysis, a brief description on the quality of dishcloths based on dirty/clean, wet/dry was recorded and the actual measurements were noted. Working under sterile conditions each dishcloth was folded in half and cut into a 5 cm × 5 cm (length × breadth) sample and placed into a sterile (Colilert® antifoam) container, for further microbial analysis.

Microbial analysis

The Colilert® Quanti-Tray®/2000 system (Iddex) was used to culture and detect the presence of coliforms and *E. coli* cells from the collected dishcloth samples. This was done by mixing each (5 × 5 cm) piece of dishcloth with 100 ml sterile distilled water and the Colilert®-18 media. The mixture (without the cloth) was then poured into the Quanti-Tray®/2000 and sealed with the Quanti-Tray® sealer followed by an incubation period of 18 hours at 37 °C. After incubation the Quanti-Trays® were placed under a 366 nm ultraviolet light for the detection of fluorescent wells, which would indicate viable *E. coli* cells. Two milliliters of the Colilert®-18 media was extracted from the positive *E. coli* Quanti-Tray® wells using a 1 ml Neomedic disposable syringe (Kendon Medical Supplies) and transferred into a 2 ml 96 well plate (Uniplate®, Whatman®). The plates were centrifuged at 13,000 ×g for 15 minutes at 4 °C to pellet out the cells. The supernatant was discarded and the pelleted cells were held at 4 °C for DNA extractions.

DNA extraction

Deoxyribonucleic acid (DNA) extractions were performed using the DX Universal Liquid Sample DNA extraction kit (Corbett Life Sciences). The pellets were resuspended with 100 μl of DX liquid digest buffer [100 μl DXL with 10% (v/v) DX digest enzyme] per well and incubated for 10 minutes at room temperature. A volume of 400 μl of DX Binding buffer with DX binding additive (w/v) was added to each well and the lysate was mixed and incubated for 5 minutes at room temperature. All the lysate was transferred to a filter plate (Unifilter®, Whatman®) placed on a manifold (Whatman®) attached to a vacuum pump (Vacuubrand, Merk). A vacuum of 25 kPa was applied to the manifold to filter out the cell debris within the wells of each plate. A volume of 200 μl of DX Binding buffer with DX Binding additive was added to each well and a vacuum of 25 kPa was applied. Each well was washed twice with 600 μl of DX Wash buffer. A further volume of 600 μl of DX Final wash buffer was added and vacuum filtered for 5 minutes at 25 kPa. A sterile 250 μl plate (Uniplate®, Whatman®) was placed inside the manifold to collect the eluted DNA. Elution buffer (150 μl) was added to each well and further incubated for 5 minutes at room temperature. The DNA was eluted by applying a 30 kPa vacuum for 1 minute. The eluted DNA was used as a template for polymerase chain reactions.

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Polymerase chain reaction

The polymerase chain reaction (PCR) method was performed using the 8-gene multiplex PCR protocol that was developed by Omar *et al.* (2010). The multiplex PCR targeted six *E. coli* groups; namely (1) ETEC containing the *lt*, and *st* gene, (2) EHEC containing the *stx1*, and *stx2* gene (3) EIEC containing the *ial* gene, (4) EAEC containing the *eagg* gene, (5) EPEC containing the *eagg* gene and (6) *E. coli* commensal containing the *mdh* gene. The primers used for the amplification of these genes and the predicted sizes are indicated in Table 2.

The *E. coli* genes were amplified using a 20 µl reaction mixture that contained 10 µl of the 2 × Qiagen® m-PCR master mix (HotstartTaq DNA polymerase, 10× buffer, 2 mM $MgCl^2$ and dNTP mix), 1 µl 5× Q-solution, 5 µl of PCR grade water, 2 µl of template DNA and 2 µl of the primer mix [0.1 µM of *Mdh* and *lt* primers (F and R), 0.2 µM of *ial* and *eagg* primers (F and R), 0.3 µM of *eaeA* and *stx2* primers (F and R), 0.5 µM of *stx1* and *st* primers (F and R)] (Table 2). PCR reactions were performed in a Biorad Mycycler™ thermal cycler under the following conditions: an initial denaturation at 95 °C for 15 minutes, denaturation at 94 °C for 45 seconds, annealing at 55 °C for 45 seconds, extension at 68 °C for 2 minutes (35 cycles) and final elongation at 72 °C of 5 minutes (Omar *et al.* 2010).

Gel electrophoresis

Amplified DNA were electrophoresed on a 2.5% (w/v) agarose gel (1.25 g agarose, 50 ml of 50 × TAE buffer [0.04 M Tris-acetate, 0.001 M EDTA, pH 8.0]), pre-stained with ethidium bromide (0.5 µg/ml) and visualized under UV illumination using the Gene Genius Bio Imaging System.

Statistical analysis

Statistical analysis was performed using Sigma Plot software Version 12.0. Data were analyzed according to the one sample *t*-test. This statistical analysis was used to determine the significance between total number of samples and experimental groups where values in the 95% confidence interval ($P < 0.05$*, $P < 0.01$** or $P < 0.001$***) were accepted as statistically different.

RESULTS

The following characteristics were noted prior to sampling of the dishcloths. Of the 424 samples collected 37% were identified as drying cloths, 63% as wash cloths and 0.7% as sponges. The sanitary status of the cloths was recorded

Table 2 | Primer sequences used in the multiplex PCR reaction and expected PCR product sizes for each gene (Omar *et al.* 2010)

Pathogen	Primer	Primer sequence (5′-3′)	Size (bp)	References
E. coli	*mdh(F)*	GGT ATG GAT CGT TCC GAC CT	300	Tarr *et al.* (2002)
	mdh(R)	GGC AGA ATG GTA ACA CCA GAG T		
EIEC	*ial(F)*	GGT ATG ATG ATG ATG AGT GGC	630	Paton & Paton (1998)
	ial(R)	GGA GGC CAA CAA TTA TTT CC		
EHEC/EPEC	*eaeA(F)*	CTG AAC GGC GAT TAC GCG AA	917	Aranda *et al.* (2004)
	eaeA(R)	GAC GAT ACG ATC CAG		
EAEC	*eagg(F)*	AGA CTC TGG CGA AAG ACT GTA TC	194	Kong *et al.* (2002)
	eagg(R)	ATG GCT GTC TGT AAT AGA TGA GAA C		
EHEC	*stx1(F)*	ACA CTG GAT CTC AGT GG	614	Moses *et al.* (2006)
	stx1(R)	CTG AAT CCC CCT CCA TTA TG		
	stx2(F)	CCA TGA CAA CGG ACA GCA GTT	779	Moses *et al.* (2006)
	stx2(R)	CCT GTC AAC TGA GCA CTT TG		
ETEC	*lt(F)*	GGC GAC AGA TTA TAC CGT GC	330	Pass *et al.* (2000)
	lt(R)	CGG TCT CTA TAT TCC CTG TT		
	st(F)	TTT CCC CTC TTT TAG TCA GTC AAC TG	160	Pass *et al.* (2000)
	st(R)	GGC AGG ATT ACA ACA AAG TTC ACA		

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as 56% dirty cloths and 44% clean cloths based on visual observations. Table 3 distinguishes the cloth type and sanitary status of dishcloths collected from different study areas.

The analyzed cloths detected total coliforms in 98 of the samples, of which 81% had bacterial counts of higher than 1,000 cfu/25 cm^2 (Table 4). In addition 42% of the cloths analyzed tested positive for the presence of *E. coli* (Table 5).

Positive *E. coli* samples were further tested for the presence of pathogenic *E. coli* strains. The results indicated that ETEC was detected in 15% of the samples, EHEC was detected in 9% of the samples, EAEC was detected in 8% of the samples, EIEC was detected in 4% of the samples and EPEC was detected in 4% of the samples. Figure 1 shows the pathogens detected from each sampling area.

DISCUSSION

From the results presented, Braamfischerville showed the highest occurrence of contamination with *E. coli*. This observation was unexpected as Braamfischerville is a relatively developed area containing recently built Reconstruction and Development Programme (RDP) housing. This could be attributed to the need for education regarding personal hygiene practices for people moving from informal settlements to the RDP housing. A study reported by Pickering *et al.* (2011) compared the bacterial count from Tanzanian houses using pit latrines containing concrete slabs to those without the concrete slabs. Their findings reported no difference of fecal contamination within the house. However, contaminants were observed in the soil. Thus although RDP houses in Braamfischerville contain latrines, education on personal hygiene is

Table 3 | Summary of the number (*n*) and type of cloths collected from each suburb along with the sanitary status of the collected cloths

		Cloth type			Sanitary status	
Sampling site	***n***	**Drying[a]**	**Washing[b]**	**Sponge[c]**	**Dirty**	**Clean**
Braamfischerville	105	28	75	2	64	41
Riverlea	101	33	67	1	46	55
Hospital Hill	143	68	75	0	92	51
Bertrams	25	8	17	0	10	15
Hillbrow	50	18	32	0	25	25

[a]Drying cloth was defined as a cloth used primarily for drying dishes, etc.
[b]Wash cloth was defined as a cloth used for washing dishes and/or surfaces.
[c]Sponge was defined as any type of sponge that may be used for cleaning dishes.

Table 4 | Distribution of total coliform counts observed on the 25 cm^2 piece of cloth tested per suburb

		Total coliform counts observed per 25 cm^2 (cfu/100 ml)					
Sampling site	***n***	**< 1**	**1–10**	**11–100**	**101–1000**	**1001–2000**	**> 2000**
Braamfischerville	105	4 (3.8)	2 (1.9)	5 (4.8)	2 (1.9)	1 (0.9)	91 (86.7)
Riverlea	101	1 (0.9)	6 (5.9)	3 (2.9)	9 (8.9)	5 (4.9)	77 (76.2)
Hospital Hill	143	4 (2.8)	9 (6.3)	10 (7)	9 (6.3)	9 (6.3)	102 (71.3)
Bertrams	25	0 (0)	0 (0)	3 (12)	2 (8)	0 (0)	20 (80)
Hillbrow	50	1 (2)	4 (8)	3 (6)	4 (8)	0 (0)	38 (76)

The percentage for each total coliform grouping per suburb is shown in brackets.
Cfu: colony forming unit.

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Table 5 | Distribution of *E. coli* counts observed on the 25 cm^2 piece of cloth tested per suburb

		***E. coli* counts observed per 25 cm^2 (cfu/100 ml)**					
Sampling site	***n***	**<1**	**1–10**	**11–100**	**101–1,000**	**1001–2,000**	**$>2,000$**
Braamfischerville	105	49 (46.7)	6 (5.7)	11 (10.5)	10 (9.5)	4 (3.8)	25 (23.8)
Riverlea	101	68 (67.3)	7 (6.9)	8 (7.9)	7 (6.9)	0 (0)	11 (10.9)
Hospital Hill	143	92 (64.3)	21 (14.7)	3 (2.1)	8 (5.6)	3 (2.1)	16 (11.2)
Bertrams	25	16 (64)	4 (16)	1 (4)	0 (0)	0 (0)	4 (16)
Hillbrow	50	30 (60)	8 (16)	3 (6)	2 (4)	1 (2)	6 (12)

The percentage for each total coliform grouping per suburb is shown in brackets.
Cfu: colony forming unit.

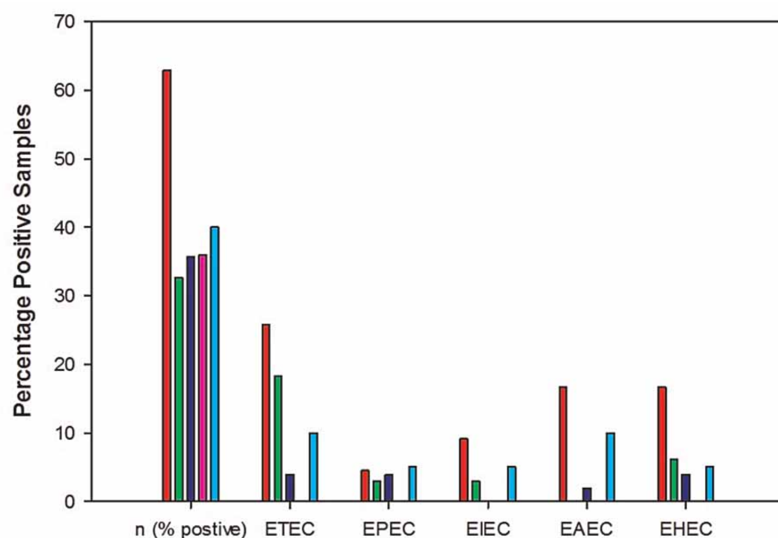

Figure 1 | Distribution of the pathogenic *E. coli* strains in the five suburbs detected from the *E. coli* positive samples.

particularly needed to prevent unsanitary practices within homes. Furthermore, Sinclair & Gerba (2010) conclude that containing an improved latrine lessens the potential contamination burden but is not effective on its own. It additionally requires people to practice sanitary conditions, have improved water systems, control the household climate and perform cleaning activities regularly.

Although such activities are generally practiced within households, it was interesting to note that bacteria on contaminated dishcloths survived 24–48 hours after drying. Kagan *et al.* (2002) stated that drying the cloths alone is not an indication of hygienic practices. Furthermore, Mattick *et al.* (2003a, 2003b) state that the temperature of water used to wash dishcloths and tea towels is generally below 40 °C which is not efficient to destroy bacterial

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contaminants and hence plays an important role in the spread of microorganisms around the household.

Moreover, Ojima *et al.* (2002) along with Beltran *et al.* (2013) stated that cleaning dishcloths with regular detergent or soaps is not sufficient to destroy pathogenic strains and suggested soaking the dishcloths in sodium hypochlorite followed by a wash in water or a dishwasher with a temperature above 40 °C. If such a protocol is applied in cleaning dishcloths within households, the bacterial load would be significantly reduced.

Areas such as Bertrams and Hillbrow had a variation of bacterial counts for total coliforms as well as pathogenic *E. coli.* However no pathogenic *E. coli* was detected from samples collected from Bertrams; this was unexpected as these regions lack access to improved water sources as well as latrines. However, the occurrence of total coliforms may indicate the occurrence of other pathogenic bacteria and requires further analysis.

Understanding the movement of bacteria in low income households in Africa is important for the development of hygienic programs and education. The source tracking of bacterial contamination within households can be done using several protocols and would assist in getting a better idea of how the bacteria are spread. However, to discontinue the spread of contaminants within the household and surrounding environment Curtis *et al.* (2003) suggest that a multidisciplinary method is required if hygienic programs are to be designed.

CONCLUSION

The results in this study indicate that there is a need for public education regarding hygiene in the households. Bacterial contamination is inevitable in such conditions and hence requires urgent attention to achieve the MDGs.

It has been demonstrated that dishcloths are important indicators of hygienic status in the households especially if the same cloth is used for various tasks. The presence of both total coliforms and *E. coli* in the samples can also indicate the presence of other pathogens further increasing the risk for diarrhea and other related infections.

Since all the diarrheagenic *E. coli* strains detected from the dishcloths can be accepted as culturable, due to the enrichment step, there is a danger of contamination of food and surfaces exposed to the dishcloths. Such occurrences may indicate the source of pathogens traveling into water and food sources contributing to diarrheal outbreaks.

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REFERENCES

Aiello, A. E., Larson, E. L. & Sedlak, R. 2008 Personal health bringing hygiene home. *American Journal of Infection Control* **36**, S152–S165.

Aranda, K. R. S., Fagundes-Neto, U. & Scaletsky, I. C. A. 2004 Evaluation of Multiplex PCR's for diagnosis of infection with diarrheagenic *Escherichia coli* and *Shigella* spp. *Journal of Clinical Microbiology* **42**, 5849–5853.

Beltran, M. S., Edeza, M. J., Viera, C., Martinez, C. I. & Chaidez, C. 2013 Sanitizing alternatives for *Escherichia coli* and *Salmonella typhimurium* on bell peppers at household kitchens. *International Journal of Environmental Research* **23**, 331–341.

Bloomfield, S. F., Aiello, A. E., Cookson, B., O'Boyle, C. & Larson, E. L. 2007 The effectiveness of hand hygiene procedures in reducing the risks of infections in home and community settings including handwashing and alcohol-based hand sanitizers. *Infection Control and Epidemiology* **35**, 27–64.

Chang, H., Ko, E. & Ju, S. 2013 Effectiveness of a dry kitchen system on controlling the microbiological safety of food and contact surfaces. *Food Science and Biotechnology* **22**, 1137–1144.

Curtis, V., Biran, A., Deverell, K., Hughes, C., Bellamy, K. & Drasar, B. 2003 Hygiene in the home: relating bugs and behavior. *Social Science and Medicine* **57**, 657–672.

Donnenberg, M. S. 2002 *Infections Caused by Escherichia coli and Other Enteric Gram-Negative Bacilli.* Section 7, Chapter VIII. (D.C. Dale, ed.) Scientific American Medicine.

Jensen, D. A., Friedrich, L. M., Harris, L. J., Danyluk, M. D. & Schaffner, D. W. 2013 Quantifying transfer rates of

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Salmonella and *Escherichia coli* O157:H7 between fresh-cut produce and common kitchen surfaces. *Journal of Food Protection* **76**, 1530–1538.

Jong, A. E. I., Verhoeff-Bakkenes, L., Nauta, M. J. & Jonge, R. 2008 Cross-contamination in the kitchen: effect of hygiene measures. *Journal of Applied Microbiology* **105**, 615–624.

Kagan, L. J., Aiello, A. E. & Larson, E. 2002 The role of the home environment in the transmission of infectious diseases. *Journal of Community Health* **27**, 247–267.

Kong, R. Y. C., Lee, S. K. Y., Law, T. W. F., Law, S. H. W. & Wu, R. S. S. 2002 Rapid detection of six types of bacterial pathogens in marine waters by multiplex PCR. *Water Research* **36**, 2802–2812.

Liu, J., Gratz, J., Maro, A., Kumburu, H., Kibiki, G., Taniuchi, M., Howlader, A. M., Sobuz, U., Haque, R., Talukder, K. A., Qureshi, S., Zaidi, A., Haverstick, D. M. & Houpt, E. R. 2011 Simultaneous detection of six diarrhea-causing bacterial pathogens with an in-house PCR-Luminex assay. *Journal of Clinical Microbiology* **50**, 98–103.

Mattick, K., Durham, K., Domingue, G., Jorgensen, F., Sen, M., Schaffner, D. W. & Humphrey, T. 2003a The survival of foodborne pathogens during domestic washing-up and subsequent transfer onto washing-up sponges, kitchen surfaces and food. *International Journal of Food Microbiology* **85**, 213–226.

Mattick, K., Durham, K., Hendrix, M., Slader, J., Griffith, C., Sen, M. & Humphrey, T. 2003b The microbiological quality of washing-up water and the environment in domestic and commercial kitchens. *Journal of Applied Microbiology* **94**, 842–848.

Moore, G. & Griffith, C. 2006 A laboratory evaluation of the decontamination properties of microfiber cloths. *The Hospital Infection Society* **64**, 379–385.

Moses, A. E., Garbati, M. A., Egwu, A. O. & Ameh, E. J. 2006 Detection of *E. coli* O157 and O26 serogroups in human immunodeficiency virus-infected patients with clinical manifestation of diarrhoea in Maiduguri, Nigeria. *Research Journal of Medicine and Medical Sciences* **1** (4), 140–145.

Ojima, M., Toshima, Y., Koya, E., Ara, K., Tokuda, H., Kawai, S., Kasuga, F. & Ueda, N. 2002 Hygiene measures considering actual distributions of microorganisms in Japanese households. *Journal of Applied Microbiology* **93**, 800–809.

Omar, K. B., Potgieter, N. & Barnard, T. G. 2010 Development of a rapid screening method for the detection of pathogenic *Escherichia coli* using a combination of Colilert® Quanti-Trays/2000 and PCR. *Water Science and Technology: Water Supply* **10**, 7–13.

Pass, M. A., Odedra, R. & Batt, R. M. 2000 Multiplex PCR for Identification of *Escherichia coli* virulence genes. *Journal of Clinical Microbiology* **38**, 2001–2004.

Paton, A. W. & Paton, J. C. 1998 Detection and characterization of Shiga toxigenic *Escherichia coli* by using multiplex PCR assays for stx1, stx2, eaeA, enterohemorrhagic *E. coli* hlyA, rfbO111, and rfbO157. *Journal of Clinical Microbiology* **36**, 598–602.

Pickering, A. J., Julian, T. R., Mamuya, S., Boehm, A. B. & Davis, J. 2011 Bacterial hand contamination among Tanzanian mothers varies temporally and following household activities. *Tropical Medicine and International Health* **16**, 233–239.

Rayner, J., Veeh, R. & Flood, J. 2004 Prevalence of microbial biofilms on selected fresh produce and household surfaces. *International Journal of Food Microbiology* **95**, 29–39.

Rossi, E. M., Scapin, D. & Tondo, E. C. 2013 Survival and transfer of microorganisms from kitchens sponges to surfaces of stainless steel and polyethylene. *The Journal of Infection in Developing Countries* **7**, 229–234.

Scott, E. 1999 Hygiene issues in the home. *American Journal of Infection Control* **27**, 22–25.

Sharma, M., Eastridge, J. & Mudd, C. 2009 Effective household disinfection methods of kitchen sponges. *Journal of Food Control* **20**, 310–313.

Soares, V. M., Pereira, J. G., Viana, C., Izidoro, T. B. & Bersot, L. D. S. & Paes de Almeida Nogueira Pinto, J. 2012 Transfer of *Salmonella* Enteritidis to four types of surfaces after cleaning procedures and cross-contamination to tomatoes. *Food Microbiology* **30**, 453–456.

Sinclair, R. G. & Gerba, C. P. 2010 Microbial contamination in kitchens and bathrooms of rural Cambodian village households. *Letters in Applied Microbiology* **52**, 144–149.

Stauber, C. E., Walters, A., Fabiszewski de Aceituno, A. M. & Sobsey, M. D. 2013 Bacterial contamination on household toys and association with water, sanitation and hygiene conditions in Honduras. *International Journal of Environmental Research and Public Health* **10**, 1586–1597.

Tarr, C. L., Large, T. M., Moeller, C. L., Lacher, D. W., Tarr, P. I., Acheson, D. W. & Whittam, T. S. 2002 Molecular characterization of a serotype 0121:H19 clone, a distinct Shiga toxin-producing clone of pathogenic *Escherichia coli*. *Infection and Immunity* **70**, 6853–6859.

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