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Evaluation of the impact of antimicrobial hand towels on hand contamination with *Escherichia coli* among mothers in Kisumu County, Kenya, 2011–2012

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Abstract

Poor hand hygiene contributes to diarrhea in developing countries. Handwashing with soap reduces diarrhea risk, but drying hands on contaminated towels can compromise the benefits of handwashing. In response to the challenge of keeping hands clean, an antimicrobial hand towel was developed and shown to be promising in the laboratory, but has not been adequately tested in the field. We evaluated the effectiveness of an antimicrobial towel in two randomized, double-blinded crossover trials among mothers with children<5 years old in 125 households in western Kenya. In trial 1, we randomly assigned mothers to use either the treated towel or an identical untreated (placebo) towel and made surprise home visits at random times once a week for three weeks. At each visit, we tested hands for *Escherichia coli* using sterile hand rinses, then switched towel types in the two groups and repeated three weekly rounds of *E. coli* testing. In crossover trial 2, we compared *E. coli* contamination of maternal hands immediately following three different handwashing/drying procedures: soap and water + treated towel, water only + treated towel, and soap and water + air dry. There was no statistically significant difference in the level of *E. coli* contamination on maternal hands by type of towel used during trial 1 (odds ratio for treated vs untreated towel: 1.14, 95% confidence interval 0.83–1.56). In trial 2, there were no significant differences in *E. coli* contamination of maternal hands by handwashing/drying procedure. In these trials, use of antimicrobial hand towels did not prevent *E. coli* contamination of mothers' hands in Kenyan households during random testing and offered no advantages over standard handwashing and drying practices. Handwashing with soap and clean water and drying with clean towels are recommended.

Keywords

Hand hygiene; Handwashing; Hand contamination; Antimicrobial towel; *Escherichia coli*

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Conflicts of interest

All authors declare no potential conflicts of interest with respect to the authorship and/or publication of this article.

1. Introduction

Diarrheal disease is the second leading cause of death in children under five years old and is responsible for an estimated 525,000 deaths in children every year (WHO 2017). In Kenya, approximately 20% of childhood deaths are attributable to diarrheal disease (WHO 2010). Poor hygiene is an important factor that contributes to the risk of diarrhea (WHO 2010).

Handwashing with soap has been shown to reduce the risk of diarrhea, neonatal mortality, and respiratory infections (Curtis et al., 2000; Curtis and Cairncross, 2003; Rabie and Curtis, 2006; Rhee et al., 2008; Pickering et al., 2010; Luby et al., 2011; Ejemot-Nwadiaro et al., 2015). Despite demonstrable effectiveness and global efforts to promote hand hygiene, most notably the Global Handwashing Partnership for handwashing with soap (https://globalhandwashing.org/), achievement of scale has been challenging, largely because it is difficult to motivate sustained hygiene behavior change (Luby et al., 2009). Poverty, poor access to improved water supplies, relatively low educational levels, and ingrained habits can make accomplishment of behavior change with respect to handwashing and other interventions more challenging (Schilling et al., 2013). In addition, evaluating program impact has been difficult because of the lack of objective measures of adherence to recommended handwashing behaviors. Although testing of hand surfaces for *Escherichia coli* (*E.coli*) or *Enterococcus* has been attempted as an objective measure of the effectiveness of handwashing practices, results have been mixed, largely because recontamination of hands can occur quickly following handwashing in fecally-contaminated environments (Kaltenthaler et al., 1996; Luby et al., 2001; Burton et al., 2011; Ram et al., 2011). There is a clear need for innovation in handwashing technologies, behavior change methods, and evaluation approaches.

One component of handwashing that has been under-emphasized in hand hygiene promotion campaigns is hand drying (Snelling et al., 2011; Huang et al., 2012). Drying with a clean towel after handwashing is not a common practice in many countries, including Kenya, largely because clean materials for hand drying are often unavailable. In one study performed in western Kenya, investigators observed that, despite widespread promotion of air drying after washing hands, people wiped their hands, both while dirty and after handwashing, on available clothing, waistcloths, curtains, or rags (Person et al., 2013). Wet hands transfer microbes more readily than dry hands and, although drying hands on a clean towel can help remove microbes by creating friction, the use of contaminated cloth can compromise the benefits of handwashing (Patrick et al., 1997). Soiled fabric and damp materials has been linked to the spread of bacterial, viral, and fungal infections (Sehulster et al., 2003).

To address the hand-drying problem, Vestergaard (www.vestergaard.com) developed a 30 × 40 cm hand towel with antimicrobial properties that is non-toxic and stable over time (Fig. 1). Laboratory testing suggested that the antimicrobial hand towel (hereafter referred to as treated towel) may help remove *E. coli* contamination from hands, but field-testing to evaluate the impact of the treated towels on populations living in fecally-contaminated environments was needed.

In this study, we examined whether use of the treated hand towels effectively reduced *E.coli* contamination on maternal hands through two randomized crossover trials in rural and peri-urban settings in Western Kenya.

2. Materials and methods

2.1. Study design

We selected a population of 125 households to participate in two field trials. The first trial was a double-blinded, placebo-controlled, crossover trial to examine the effectiveness of the treated towel (Fig. 1) compared to an identical, untreated, placebo towel (hereafter referred to as untreated towel) in daily use through surprise home visits. The second trial was a triple cross-over trial in three rounds to explore the treated towel's effectiveness immediately following handwashing under more controlled conditions.

2.2. Study population

The trials took place in households in peri-urban and rural neighborhoods in Kisumu County, Kenya from July 2011–January 2012. During 2008–09, Kisumu County had the mortality rate for children under five years old (74 deaths per 1000 live births) and had the highest burden of diarrheal diseases in Kenya (Kenya National Bureau of Statistics, 2010).

2.3. Sample size calculation

To calculate the sample size required for the study, we assumed that at least 40% of mothers using the treated towels would have at least one $\log_{10}$ reduction of *E. coli* on their hands compared to baseline, and that mothers using untreated towels would have no reduction of *E. coli*. Using these assumptions, a confidence level of 95%, and power of 80%, we calculated a sample size of 40 persons for each of the intervention and comparison groups (80 persons in total) in trial 1. To account for attrition of 10% and the possible impact of a lack of adherence to recommended use of treated towels on the effectiveness of the intervention, we increased the estimated sample size by 50%. Thus, 60 persons were recruited for each group, yielding a total study recruitment of 120 persons.

2.4. Sample selection

In July 2011, we randomly selected twelve census enumeration areas (EAs) in Kisumu County for the treated towel evaluation; Using a full list of all EAs in Kisumu county, we generated random numbers and, after sorting the numbers in a descending order, selected the top 12 EAs. We then conducted a census of households in these 12 EAs and similarly selected a random sample of approximately 10 mothers, each with at least one child under five years of age, from each EA, enrolling a total of 125 mothers.

2.5. Trial 1

Trial 1 was conducted from July to October 2011 to determine whether daily use of the treated towel reduced *E. coli* contamination of hands following handwashing (Fig. 2). We first conducted a baseline survey of 125 participants, interviewing each participant regarding household demographic and socioeconomic characteristics, handwashing practices, and

observations on the presence of soap and handwashing technique. Following the interview, we examined participants' hands for *E.coli* using the "glove juice" method (detailed below) as baseline measures, gave each participant a free bar of soap, and provided instructions on proper handwashing technique (including the key times for handwashing). Next, the 125 participants received three weekly, unannounced home visits to obtain baseline measures. Participants were then randomly assigned into two groups (random numbers were generated; after sorting the first half was allocated into A and the rest into B). One group received a treated towel plus soap and the other group received an untreated towel plus soap. Participants were encouraged to use the towels after handwashing and whenever they needed to wipe or dry their hands. Treated and untreated towels were identical in size, shape, and color and towels were distributed in a double-blind fashion (i.e., neither the research team nor recipients knew which towel was received except one investigator). Once a week for a three-week period (round 1), the field team made a surprise home visit at random times each week to each of the enrolled women and obtained a hand rinse sample for *E. coli* testing. After the 3rd visit, the towels provided to groups A and B were removed from the homes. We then gave each group the type of towel they had not received for round 1, as well as 1 bar of soap. After a one-week "washout" period, we resumed weekly visits to obtain hand rinse samples from enrolled women for a three-week period (round 2). A total of nine visits (three for baseline, three for round 1, and three for round 2) were made per household.

We also conducted a qualitative study of towel use among 52 participants randomly selected from a household list. At the end of round 1 or 2, selected participants were invited to have an in-depth interview (IDI). If a woman declined, we continued to the next names on the list until a participant agreed to participate. Field team members included a senior behavioral scientist and research assistants with previous qualitative research experience within the communities where the study was conducted. After trial 1, treated towels and soap were distributed to the participants and they were encouraged to continue good hand hygiene practices.

2.6. Trial 2

We conducted trial 2 in January 2012 to compare three handwashing/drying methods under more controlled conditions (Fig. 2). For this study, 65 participants were randomly selected from the 125 mothers enrolled at baseline, given a free antimicrobial towel, and provided a refresher training on proper handwashing technique and towel use. Participants were randomized into three groups (A, B, or C). We made one surprise home visit to each mother during each of the three rounds, asked mothers to wash and dry their hands using the method indicated for that visit, and obtained hand rinse samples immediately afterward. The three methods were: 1) soap and water (SW) + air dry, 2) SW + treated towel, and 3) water only + treated towel. For each round, each group of mothers was assigned a different handwashing and drying method. By the end of the study, each mother had used, and had hand rinse samples tested for, each of the three methods.

2.7. Hand rinse sample collection

Participants' hands were tested for *E. coli* using a modified "glove juice" method (https://globalhandwashing.org) (Fig. 3). In the laboratory, Whirl-Pak® (Fort Atkinson, WI, USA)

bags were aseptically filled with 150 ml of sterile distilled water (eluent) and closed securely. Bags were carried in coolers to households where the hand rinses were conducted. A participant was asked to place one hand into the bag and use the other hand to secure the bag around her wrist. The sample collector then gently massaged the entire surface below the wrist of the hand inside the bag for 30 s; this was repeated within the same bag with the participant's other hand. The sample bag was then secured and transported in a cooler on ice to the laboratory where it was processed within 8 h of collection.

2.8. Escherichia coli testing

In the laboratory, each sample bag was gently mixed by inverting and 100 ml poured into sterile plastic bottles. In addition, a 1:100 dilution of sample was prepared in sterile distilled water. *E. coli* in rinse samples were quantified using IDEXX™ QuantiTray®/ 2000 (Westbrook, ME, USA) most probable number (MPN) methodology and Colilert-18® media, according to manufacturer's instructions. Positive controls (eluent water seeded with a lab-strain of *E. coli*) and lab blanks (eluent water only) were assayed each sampling day to validate test performance and to ensure lack of contamination in eluent water, respectively. Each sample was assigned into one of three categories based on estimated MPN of *E. coli* in 100 ml of hand rinse eluent: undetectable (<1 MPN), moderately contaminated (1e100 MPN), and highly contaminated (>100 MPN).

2.9. Statistical analysis

Data were collected using personal digital assistants and entered into a Microsoft Access database (Redmond, WA, USA). All statistical analyses were done using SAS v9.4 (Cary, NC, USA). Differences in demographic, socioeconomic characteristics, and hand hygiene practices between households included and excluded at baseline in each study were examined using Chi-square test for categorical variables. Fisher's exact test was used for small sample sizes; *t*-test or Wilcoxon rank-sum test were used (as appropriate) for continuous variables.

To explore associations between the hand contamination and treated towel use in trial 1, ordinal logistic regression was applied by treating the three contamination levels (<1, 1–100, >100 MPN/100 ml hand rinse eluent) as an ordinal outcome variable, and the type of towel used for drying hands (baseline, treated towel, untreated towel) as an exposure variable. Similarly, in trial 2, the same analysis was applied treating the three contamination levels as an ordinal outcome variable, and the handwashing/drying method (SW + air dry, SW + towel, or water only + towel) as an exposure variable. The standard handwashing method, SW + air dry was set as a reference category.

We examined covariates, including mothers' age (≤20, >20 to ≤26, >26 years), education level (completed primary or less, secondary or higher), having electricity at household (yes or no), having children (≥2) under five years old (=1 or 0), observed latrine at home (yes or no), and having an improved water source (including borehole, rain water catchment, covered well, piped water, protected spring) (yes or no) for both trials. In addition, to address possible correlations from the repeated home visits in the same household we used the generalized estimating equation approach to analyze the data (Liang and Zeger, 1986).

In the IDI of trial 1, audio recordings and handwritten field notes were used for data collection from 52 participants and then reviewed during debriefing sessions. Data were transcribed and translated into English by bilingual research assistants, and entered as Microsoft Word documents into Atlas-ti (Atlasti.com) to facilitate text searching and data coding.

2.10. Ethical considerations

The study protocol was reviewed and approved by the Centers for Disease Control and Prevention Institutional Review Board (protocol number 6102) and the Ethical Review Committee of the Kenya Medical Research Institute (protocol number 2033). Oral informed consent was obtained from all study participants in their native languages (Luo or Luhya) and personal identifiers were irretrievably destroyed at the conclusion of the study.

3. Results

3.1. Demographic and socioeconomic variables

At baseline, the mean age of 125 participants was 24.1 (standard deviation, 6.9) years; 77% attained a primary or lower level of education and 66% had more than one child under five years of age (Table 1). Of 125 participants, 18 (14%) had electricity at home, 95 (76%) homes had walls made of dung/mud, and 117 (94%) had a latrine (either private or shared). While 81% reported using an improved water source, only 19% reported using safe water storage containers (i.e., plastic jerry can or improved clay pot with a narrow mouth and tap). Overall, about half of participants (51.2%) lived in a rural area.

3.2. Trial 1

A total of 22 participants were excluded from analysis (Table 1); households were excluded if they had one or fewer home visit during the testing rounds. The only statistically significant difference between included and excluded participants was average age (24.8 years vs 21.0 years, $p = 0.05$). There were no differences in reported frequency of daily handwashing practices, possession of soap, and ability to demonstrate proper handwashing procedure (Table 2). Although a relatively high percentage of both included and excluded participants reported washing hands after using the toilet or before eating, only 31% of included participants and 59% of excluded participants reported handwashing before food preparation.

At baseline, by weekly home visit, 27%e36% of maternal hands were highly contaminated with *E. coli* (>100 MPN/100 ml hand rinse eluent) (Table 3). Following distribution of towels, among participants using treated towels, high contamination rates varied from 38% to 46% weekly, and were similar to rates measured among participants using untreated towels (39%–42%).

The odds of maternal hands exhibiting increased *E.coli* contamination levels were similar between participants who used treated and those who used untreated towels (OR [95% CI] = 1.14 [0.83–1.56], $p = 0.41$), after adjusting for maternal age and education, having children under five years old, having electricity, having a latrine at home, or using an improved water

source (Table 4). Similarly, there was no difference in the odds of maternal hands exhibiting higher level of *E.coli* contamination, regardless of whether participants used the untreated towel or their traditional hand washing and drying method at baseline (OR = 0.80, 95% CI = 0.58–1.09). Mothers who lived in homes with electricity had lower odds of having greater *E.coli* contamination of hands than mothers who did not (OR = 0.52 [0.28–0.96], p = 0.04). Maternal age and education, having children under five years old in the household, having a latrine at home, or using an improved water source were not associated with increased *E.coli* contamination on maternal hands.

Almost all the women in IDIs were the main users of the distributed towel and reported using it throughout the day especially when their hands were wet. Three-fourths of the women reported hanging their towel in the house where they could see it and easily access it while doing daily household chores. Women reported washing their towel from one to three times per day.

3.3. Trial 2

Sixty participants from trial 1 were randomly excluded by design for trial 2 (Table 1). Included participants (n = 65) had a higher mean age (25.3 years vs 22.9 years, p = 0.03), and were more likely to have a cell phone (92.3% vs 78.3%, p = 0.03) and live in a rural area (60.0% vs 41.7%, p = 0.04) than excluded participants. There were no differences in included and excluded participants in possession of soap or in ability to demonstrate proper handwashing procedures (Table 2). Although a high percentage of both included and excluded participants reported washing hands after using the toilet or before eating, less than 40% in both groups reported handwashing before cooking.

Overall, hand rinses had similar rates of undetectable or moderate *E. coli* contamination (≤100 MPN/100 ml hand rinse eluent) by handwashing technique, including soap/water + air dry (85.7%), soap/water + treated towel (80.9%), and water only + treated towel (81.5%) (Table 5). The percentage of hand rinse samples exhibiting high levels of *E.coli* (>100 MPN/100 ml hand rinse eluent) ranged from 14.3% when mothers used soap/water + air dry to 19.1% when using soap/water +treated towel, to 18.5% when using water only treated towel. The odds of maternal hands exhibiting a higher level of *E. coli* contamination were not statistically different among the three handwashing and drying methods used by participants (Table 6). Similarly, no covariates were associated with detectable *E.coli* contamination on participants' hands.

4. Discussion

Findings from these field studies suggested that use of antimicrobial towels for drying did not reduce the odds of *E. coli* contamination on mothers' hands compared to use of untreated towels. The use of treated towels did not reduce the level of contamination observed during random hand testing, a result that has been observed in at least three other studies of handwashing with soap (Pickering et al., 2010, 2011; Ram et al., 2011; Slayton et al., 2016), nor did they confer an advantage when microbiologic testing was conducted immediately following handwashing.

There are several possible explanations for the lack of effectiveness of the treated towel in decreasing *E.coli* contamination of maternal hands. First, the treated towels themselves might have acted as fomites. Although similar technology used in treated towels has been demonstrated in the laboratory to have antimicrobial properties (Gerba et al., 2012), bacterial colonization of towels may have taken place during household use in the fecally-contaminated environments of study communities (Slayton et al., 2016), and the towels may have reintroduced *E. coli* to participants' hands between handwashing and hand rinse sampling. This potential explanation, however, does not explain the findings in trial 2, in which air drying after washing with soap and water did not diminish contamination compared to treated towel use after washing with soap and water. Second, it is possible that the handwashing technique among study participants was poor and facilitated recontamination. For example, total removal of *E. coli* may not occur after handwashing because some organisms may lie beyond the reach of handwashing (e.g., under fingernails). However, women were given instructions for proper handwashing at the beginning of both studies and, in both studies, handwashing technique was observed before collecting the hand rinse samples and found to be adequate. Finally, the water used for handwashing in these homes may have been contaminated with *E. coli*, which could have contributed to hand recontamination during rinsing. At least one other study has found an association between stored water quality and hand contamination (Pickering et al., 2010). Unlike that study, which took place in an area of Tanzania where participants used improved water sources (i.e. bottled, borewell, or municipal tap), most of our study participants' reported unsafe water storage practices and one-fifth reported using unimproved water sources.

The results of this evaluation are consistent with studies of handwashing with antimicrobial soap that have shown no difference in bacterial contamination of hands and no health impact compared to untreated soap (Luby et al., 2004, 2005; Aiello et al., 2007), despite other studies that suggested that use of antimicrobial soap reduced bacterial contamination (Paulson, 1994; Sickbert-Bennett et al., 2004). Furthermore, in trial 2, use of the treated towel following handwashing with soap and water did not perform better than use of treated towel following handwashing with water alone. Results of studies of antimicrobial soap and hand towels do not justify widespread promotion of these products, which tend to be more expensive than traditional alternatives (Aiello et al., 2007; Slayton et al., 2016). Further evaluation is necessary to determine whether other types of health benefits are obtained from use of treated towels.

The importance of hygienic hand drying to effective handwashing has not been adequately addressed (Snelling et al., 2011; Huang et al., 2012; Person et al., 2013). Although inexpensive towels or cloths are readily available in most settings, safe use requires frequent washing and, consequently, multiple towels in each household to ensure availability (Gerba et al., 2014), which may be challenging for low income families with limited disposable income and time (Schilling et al., 2013). Similarly, use of disposable towels is not economically sustainable for many families in the developing world. More research into novel hand drying technologies or implementation approaches is needed.

This study had several important limitations. First, placement of treated towels in the household, which we did not systematically observe during all visits, may have influenced

study results. Several women in IDIs said they kept the towels in the most accessible places such as the kitchen or on the wall. Towels located in kitchens might have been used not only for hand drying, but also during food preparation, cooking, or wiping surfaces and could have resulted in increased contamination and transmission of bacteria to maternal hands (Gerba et al., 2014). Second, frequency of towel washing, which has been correlated to degree of contamination with *E. coli* (Gerba et al., 2014), might have affected microbiological results. In trial 1, towels were observed to be dirty in more than a third of home visits, but we excluded observable dirtiness of towels as a covariable in our analysis because of a high missing rate. It appears that, although the antimicrobial towels were designed to reduce the need for washing, towel cleanliness continues to be important for effective hand hygiene. Third, we did not obtain data on the activities of mothers immediately before towel use or handwashing, such as changing babies' nappies, which could have affected the results. We addressed the difficulty of adequately identifying the many behaviors that potentially could have contaminated the towel by using a randomized double-blinded crossover design to reduce inter-subject variability. Fourth, we excluded participants who had two or more missing home visits per round in trial 1, which could have contributed to selection bias. The missing home visits occurred because of our study design (i.e., the visits took place at random times during the day); some women went to market days or moved away, which were independent of hand hygiene efficacy. In a separate sensitivity analysis including those who only had one visit per round, the results remained similar (data not shown). Fifth, by design in trial 2, we did not observe the method women used for handwashing and drying between our visits. Although the women were given a treated towel to use, they could have used their habitual drying method instead, which would have confounded the microbiological results. Finally, because the study population was limited to a relatively small sample of 125 mothers or less in Kisumu County, the results may not be generalizable to other similar populations. In addition, only 65 mothers included in trial 2 was subject to the decreased statistical power.

5. Conclusion

This study aimed at investigating the potential use of the anti-microbial hand towels to reduce *E.coli* contamination on maternal hands.

- Results presented in this study did not support a direct association between treated towel use and reduced *E. coli* contamination on maternal hands under field conditions in Western Kenyan communities.
- Considering the absence of effective novel technologies for hand drying and the likelihood that air drying is inconsistently practiced, hand drying methods remain an important component of hand hygiene; however, for hand towel use to improve hand hygiene, towel cleanliness can only be ensured through regular washing and drying.
- Hand drying has not typically been considered in studies of the impact of hand hygiene on health, but deserves increased attention in further evaluations.

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References

Aiello AE, Larson EL, Levy SB, 2007 Consumer antibacterial soaps: effective or just risky? Clin. Infect. Dis 45 (Suppl. 2), 137–147.

Burton M, Cobb E, Donachie P, Judah G, Curtis V, Schmidt W-P, 2011 The effect of handwashing with water or soap on bacterial contamination of hands. Int. J. Environ. Res. Public Health 8 (1), 97–104. [PubMed: 21318017]

Curtis V, Cairncross S, 2003 Effect of washing hands with soap on diarrhoea risk in the community: a systematic review. Lancet Infect. Dis 3, 275–281. [PubMed: 12726975]

Curtis V, Cairncross S, Yonli R, 2000 Domestic hygiene and diarrhoea - pin- pointing the problem. Trop. Med. Int. Health 5, 22–32. [PubMed: 10672202]

Ejemot-Nwadiaro RI, Ehiri JE, Arikpo D, Meremikwu MM, Critchley JA, 2015 Hand washing promotion for preventing diarrhoea. Cochrane Database Syst. Rev 3 (9), 1–95.

Gerba CP, Sifuentes LY, Maxwell S, Sakurada T, 2012 Antibacterial efficacy of TiO2/Ag treated fabrics. Househ. Personal Care Today 7 (3), 24–27.

Gerba CP, Tamimi AH, Maxwell S, Sifuentes LY, Hoffman DR, Koenig DW, 2014 Bacterial occurrence in kitchen hand towels. Food Prot. Trends 34 (5), 312–317.

Huang C, Ma W, Stack S, 2012 The hygienic efficacy of different hand-drying methods: a review of the evidence. Mayo Clin. Proc 87 (8), 791–798. [PubMed: 22656243]

Kaltenthaler EC, Drasar BS, Potter CW, 1996 The use of microbiology in the study of hygiene behavior. Microbios 88, 35–43. [PubMed: 9121378]

Kenya National Bureau of Statistics (KNBS) and ICF Macro, 2010 Kenya Demographic and Health Survey 2008–09 KNBS and ICF Macro, Calverton, Maryland.

Liang KY, Zeger SL, 1986 Longitudinal data analysis using generalized linear models. Biometrika 73 (1), 13–22.

Luby SP, Agboatwalla M, Raza A, Sobel J, Mintz ED, Baier K, Hoekstra RM, Rahbar MH, Hassan R, Qureshi SM, Gangarosa EJ, 2001 Microbiologic effectiveness of hand washing with soap in an urban squatter settlement, Karachi, Pakistan. Epidemiol. Infect 127, 237–244. [PubMed: 11693501]

Luby SP, Agboatwalla M, Painter J, Altaf A, Billhimer WL, Hoekstra RM, 2004 Effect of intensive handwashing promotion on childhood diarrhea in high-risk communities in Pakistan: a randomized controlled trial. J. Am. Med. Assoc 291 (21), 2547–2554.

Luby SP, Agboatwalla M, Feikin DR, Painter J, Billhimer W, Altaf A, Hoekstra RM, 2005 Effect of handwashing on child health: a randomised controlled trial. Lancet 366 (9481), 225–233. [PubMed: 16023513]

Luby SP, Agboatwalla M, Bowen A, Kenah E, Sharker Y, Hoekstra RM, 2009 Difficulties in maintaining improved handwashing behavior, Karachi, Pakistan. Am. J. Trop. Med. Hyg 81, 140–145. [PubMed: 19556579]

Luby SP, Halder AK, Huda T, Unicomb L, Johnston RB, 2011 The effect of handwashing at recommended times with water alone and with soap on child diarrhea in rural Bangladesh: an observational study. PLoS Med 8, e1001052. [PubMed: 21738452]

Patrick DR, Findon G, Miller TE, 1997 Residual moisture determines the level of touch-contact-associated bacterial transfer following hand washing. Epidemiol. Infect 119, 319–325. [PubMed: 9440435]

Paulson DS, 1994 A comparative evaluation of five surgical hand scrub preparations. AORN J 60 (246), 249–256.

Person B, Schilling K, Owuor M, Ogange L, Quick R, 2013 A qualitative evaluation of hand drying practices among Kenyans. PLoS One 8 (9), e74370. [PubMed: 24069302]

Pickering AJ, Davis J, Walters SP, Horak HM, Keymer DP, Mushi D, Strickfaden R, Chynoweth JS, Liu J, Blum A, Rogers K, Boehm AB, 2010 Hands, water, and health: fecal contamination in Tanzanian communities with improved, non-networked water supplies. Environ. Sci. Technol 44, 3267–3272. [PubMed: 20222746]

Pickering AJ, Julian TR, Mamuya S, Boehm AB, Davis J, 2011 Bacterial hand contamination among Tanzanian mothers varies temporally and following household activities. Trop. Med. Int. Health 16 (2), 233–239. [PubMed: 21091858]

Rabie T, Curtis V, 2006 Handwashing and risk of respiratory infections: a quantitative systematic review. Trop. Med. Int. Health 11, 258–267. [PubMed: 16553905]

Ram PK, Jahid I, Halder AK, Nygren B, Islam MS, Granger SP, Molyneaux JW, Luby SP, 2011 Variability in hand contamination based on serial measurements: implications for assessment of hand-cleansing behavior and disease risk. Am. J. Trop. Med. Hyg 84 (4), 510–516. [PubMed: 21460002]

Rhee V, Mullany LC, Khatry SK, Katz J, LeClerq SC, Darmstadt GL, Tielsch JM, 2008 Maternal and birth attendant hand washing and neonatal mortality in southern Nepal. Arch. Pediatr. Adolesc. Med 162, 603–608. [PubMed: 18606930]

Schilling K, Person B, Faith SH, Otieno R, Quick R, 2013 The challenge of promoting interventions to prevent disease in impoverished populations in rural western Kenya. Am. J. Public Health 103 (12), 2131–2135. [PubMed: 24188638]

Sehulster L, Chinn RY, CDC, HICPAC, 2003 Guidelines for environmental infection control in health-care facilities. Recommendations from CDC and the healthcare infection control practices advisory committee (HICPAC). MMWR Recomm. Rep. (Morb. Mortal. Wkly. Rep.) 6, 1–42, 52(RR-10) https://npin.cdc.gov/publication/mmwr-guidelines-environmental-infection-control-health-care-facilities-recommendations.

Sickbert-Bennett EE, Weber DJ, Gergen-Teague MF, Rutala WA, 2004 The effects of test variables on the efficacy of hand hygiene agents. Am. J. Infect. Contr 32, 69–83.

Slayton RB, Murphy JL, Morris J, Faith SH, Oremo J, Odhiambo A, Ayers T, Feinman SJ, Brown AC, Quick RE, 2016 A cluster randomized controlled evaluation of the health impact of a novel antimicrobial hand towel on the health of children under 2 Years old in rural communities in Kisumu county, Kenya. Am. J. Trop. Med. Hyg 94 (2), 437–444. [PubMed: 26643530]

Snelling AM, Saville T, Stevens D, Beggs CB, 2011 Comparative evaluation of the hygienic efficacy of an ultra-rapid hand dryer vs conventional warm air hand dryers. J. Appl. Microbiol 110 (1), 19–26. [PubMed: 20887403]

WHO Media centre, May 2017 Diarrhoeal Disease, Fact Sheet http://www.who.int/mediacentre/factsheets/fs330/en/. (Accessed 20 May 2018).

WHO World Health, 2010 Statistics http://www.who.int/gho/publications/world_health_statistics/EN_WHS10_Full.pdf. (Accessed 27 April 2018).

Fig. 1.
Antimicrobial (treated) hand towel, 30 cm × 40 cm (untreated towel was identical).

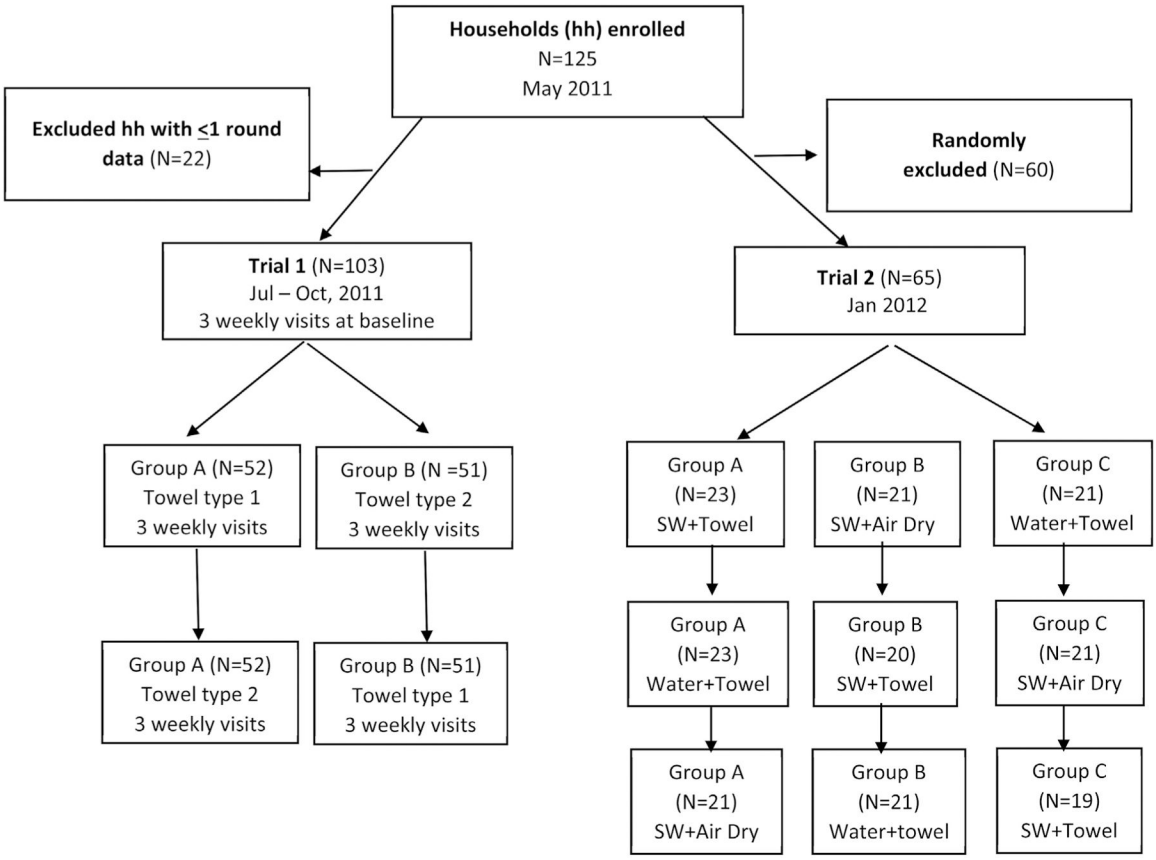

Fig. 2.

Flowchart of the study design for Hand Towel Trial 1 and 2—Kisumu County, Kenya, 2011–2012; Ns in parenthesis differ because of missing home visits; SW means Soap & Water.

Fig. 3.
Hand rinse sampling from mothers using the glove juice method—Kisumu County, Kenya, 2011–2012.

Table 1

Demographic and socioeconomic characteristics of households included and excluded from the study, at baseline, and trial, N (%) or Mean [±Standard deviation]—Kisumu County, Kenya, 2011–2012.

	All	Trial 1			Trial 2		
		Included	Excluded	*P*	Included	Excluded	*P*
All	125	103	22		65	60	
Age of mothers, years	24.1 [±6.9]	24.8 [±7.3]	21.0 [±3.3]	**0.05**	25.3 [±7.4]	22.9 [±6.2]	**0.02**
≤20	45 (36.0)	33 (32.0)	12 (54.6)		17 (26.2)	28 (46.7)	
>20 to ≤26	45 (36.0)	37 (35.9)	8 (36.4)		24 (36.9)	21 (35.0)	
>26	35(28.0)	33 (32.0)	2 (9.1)		24 (36.9)	35 (18.3)	
Education level				0.95			0.10
Primary or less	96 (76.8)	79 (76.7)	17 (77.3)		46 (70.8)	50 (83.3)	
Secondary or higher	29 (23.2)	24 (23.3)	5 (22.7)		19 (29.2)	10 (16.7)	
No. of children <5 yr				0.49			0.28
1	42 (33.6)	36 (27.3)	6 (35.0)		19 (29.2)	23 (38.3)	
>1	83 (66.4)	67 (72.7)	16 (65.0)		46 (70.8)	37 (61.7)	
Electricity at home	18 (14.4)	16 (15.5)	2 (9.1)	0.74	13 (20.0)	5 (8.3)	0.07
Asset ownership							
TV	24 (19.2)	20 (19.4)	4 (18.2)	0.89	15 (23.1)	9 (15.0)	0.25
Radio	88 (70.4)	73 (70.9)	15 (68.2)	0.80	49 (75.4)	39 (65.0)	0.20
Motorcycle	54 (43.2)	45 (43.7)	9 (40.9)	0.81	29 (44.6)	25 (41.7)	0.74
Refrigerator	2 (1.6)	1 (1.0)	1 (4.6)	0.32	1 (1.5)	1 (1.7)	0.99
Cell phone	107 (85.6)	90 (87.4)	17 (77.3)	0.22	60 (92.3)	47 (78.3)	**0.03**
Wall material				0.99			0.91
Dung/Mud	95 (76.0)	78 (75.7)	17 (77.3)		50 (76.9)	45 (75.0)	
Metal	1 (0.8)	1 (1.0)	0 (0.0)		1 (1.5)	0 (0.0)	
Bricks/stones	29 (23.2)	24 (23.3)	5 (22.7)		14 (21.5)	15 (25.0)	
Roof material				0.12			0.88
Thatch	12 (9.6)	12 (11.6)	0 (0.0)		7 (10.8)	5 (8.3)	
Metal	111 (88.8)	90 (87.4)	21 (95.5)		57 (87.7)	54 (90.0)	
Tile	2 (1.6)	1 (1.0)	1 (4.5)		1 (1.5)	1 (1.7)	

	All	Trial 1			Trial 2		
		Included	Excluded	*P*	Included	Excluded	*P*
Latrine at home	117 (93.6)	97 (94.2)	20 (90.9)	0.63	62 (95.4)	55 (91.7)	0.48
[a]Improved water source	101 (80.8)	84 (81.5)	17 (77.3)	0.64	53 (81.5)	48 (80.0)	0.83
[b]Safe Water storage	24 (19.2)	19 (18.5)	5 (22.7)	0.77	13 (20.0)	11 (18.3)	0.81
Type of settlement				0.90			**0.04**
Rural	64 (51.2)	53 (51.5)	11 (50.0)		39 (60.0)	25 (41.7)	
Urban	61 (48.8)	50 (48.5)	11 (50.0)		26 (40.0)	35 (58.3)	

Bold indicates significant at $P \leq 0.05$.

[a]Includes borehole, rain water catchment, covered well, piped water, protected spring.

[b]Plastic jerry can or improved clay pot (narrow mouth with tap).

Table 2

Reported and observed hand hygiene practices of households at baseline: overall, and by trial, n (%)—Kisumu County, Kenya, 2011–2012.

	All (n = 125)	Trial 1			Trial 2		
		Included (n = 103)	Excluded (n = 22)	*P*	Included (n = 65)	Excluded (n = 60)	*P*
Reported critical times for handwashing							
After visiting toilet	87 (69.6)	72 (70.0)	15 (68.2)	0.87	46 (70.8)	41 (68.3)	0.77
Before eating	105 (84.0)	88 (85.4)	17 (77.3)	0.34	54 (83.1)	51 (85.0)	0.77
Before food preparation	45 (36.0)	32 (31.1)	13 (59.1)	**0.01**	24 (36.9)	21 (35.0)	0.82
After farm work	11 (8.8)	9 (8.7)	2 (9.1)	0.99	6 (9.2)	5 (8.3)	0.86
No. reported washing hands yesterday				0.41			0.89
≤2 times	13 (10.4)	11 (10.7)	2 (9.1)		6 (9.2)	7 (11.7)	
3–4 times	58 (46.4)	45 (42.7)	13 (59.1)		31 (47.7)	27 (45.0)	
≥ 5 times	54 (43.2)	47 (45.6)	7 (31.8)		28 (43.1)	26 (43.3)	
Bar soap observed	100 (80.0)	84 (81.6)	16 (72.7)	0.35	55 (84.6)	45 (75.0)	0.18
Handwashing observation							
Uses soap	93 (74.4)	78 (75.7)	15 (68.2)	0.46	47 (72.3)	46 (76.7)	0.58
Lather thoroughly	80 (64.0)	66 (64.1)	14 (63.6)	0.97	41 (63.1)	39 (65.0)	0.82
Air dries	81 (64.8)	66 (64.1)	15 (68.2)	0.71	44 (67.7)	37 (61.7)	0.48
Towel	9 (7.2)	9 (8.7)	0 (0.0)	0.36	6 (9.2)	3 (5.0)	0.36

Bold indicates statistically significant at 0.05 level.

Table 3

Number[a] and percentage of maternal hands exhibiting *E.coli* on hand rinse, by contamination level and intervention, during weekly home visits, Hand Towel Trial 1—Kisumu County, Kenya, 2011 (N = 103 subjects).

	Visit 1, MPN[b]			Visit 2, MPN[b]			Visit 3, MPN[b]			Total, MPN[b]		
	<1	1–100	>100	<1	1–100	>100	<1	1–100	>100	<1	1–100	>100
Baseline	24(23.3)	51(49.5)	28(27.2)	23(23.7)	41(42.3)	33(34.0)	21(21.4)	42(42.9)	35(35.7)	68(22.8)	134(45.0)	96(32.2)
Treated towel	18(20.2)	35(39.3)	36(40.5)	21(23.3)	35(38.9)	34(37.8)	12(12.6)	39(41.1)	33(46.3)	51(18.6)	109(39.8)	114(41.6)
Untreated towel	19(20.0)	36(37.9)	40(42.1)	23(24.2)	35(36.8)	37(39.0)	19(19.4)	43(43.9)	36(36.7)	61(21.2)	114(39.6)	113(39.2)

[a]Varies by visit and treatment group because of absence of mothers at the time of visit.

[b]*E. coli*/100 ml hand rinse eluent.

Table 4

Adjusted odds ratio (OR) of maternal hands exhibiting increased *E. coli* contamination, by type of towel used and covariates, Hand Towel Trial 1—dKisumu County, Kenya, 2011

	OR (95% CI[a])	*P*
Towel used		
Baseline (usual practice)	0.80 (0.58–1.09)	0.15
Treated towel	1.14 (0.83–1.56)	0.41
Untreated towel	Ref[b]	
Age of mothers, years		
≤ 20	1.28 (0.83–1.97)	0.27
>20 to ≤ 26	1.41 (0.93–2.16)	0.11
> 26	Ref[b]	
Education level		
Completed primary or less	Ref[b]	
Secondary or higher	0.98 (0.61–1.58)	0.93
Electricity at household	0.52 (0.28–0.96)	**0.04**
Have children under 5 years old	0.96 (0.65–1.44)	0.86
Latrine at home	1.06 (0.44–2.57)	0.90
Improved water source	0.88 (0.51–1.52)	0.65

Bold indicates statistical significance at level 0.05.

[a]Confidence Interval.

[b]Reference.

Table 5

Number and percentage of maternal hands exhibiting *E. coli* on hand rinse, by contamination level and handwashing and drying method, during home visits in three day period, Hand Towel Trial 2—Kisumu County, Kenya, 2012

	Visit 1, MPN (N = 65)			Visit 2, MPN (N = 64)[a]			Visit 3, MPN (N = 62)[a]			Total, MPN (N = 65)[a]		
	<1	1–100	>100	<1	1–100	>100	<1	1–100	>100	<1	1–100	>100
SW[b] + Air Dry	5(23.8)	10(47.6)	6(28.6)	3(14.3)	16(76.2)	2(9.5)	13(61.9)	7(33.3)	1(4.8)	21(33.3)	33(52.4)	9(14.3)
SW[b] + Towel	10(43.5)	8(34.8)	5(21.7)	9(45.0)	5(25.0)	6(30.0)	10(50.0)	9(45.0)	1(5.0)	29(46.0)	22(34.9)	12(19.1)
Water + Towel	6(28.6)	9(42.9)	6(28.6)	7(30.4)	13(56.5)	3(13.0)	9(42.9)	9(42.9)	3(14.3)	22(33.8)	31(47.7)	12(18.5)

[a] Visits 2 and 3 had missing values because of absence of mothers at the time of visit.

[b] Soap & Water.

Table 6

Adjusted odds ratio (OR) of maternal hands exhibiting increased *E. coli* contamination, by handwashing and drying method and covariates, Hand Towel Trial 2—Kisumu County, Kenya, 2012

	OR (95% CI[a])	*P*
Handwashing methods		
SW[c] + Air Dry	Ref[b]	
SW[c] + Towel	0.75 (0.41e1.40)	0.36
Water + Towel	1.05 (0.59e1.85)	0.88
Age of mothers, years		
≤ 20	1.56 (0.70e3.48)	0.28
>20 to ≤ 26	1.56 (0.72e3.41)	0.26
> 26	Ref[b]	
Education level		
Completed primary or less	Ref[b]	
Secondary or higher	0.76 (0.35e1.66)	0.49
Electricity at household	0.65 (0.17e1.59)	0.35
Have children under 5 years old	0.92 (0.42–2.00)	0.70
Latrine at home	0.81 (0.28–2.36)	0.70
Improved water source	0.67 (0.31–1.46)	0.31

[a]Confidence Interval.

[b]Reference.

[c]Soap & Water.