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Evaluating four measures of water quality in clay pots and plastic safe storage containers in Kenya

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ABSTRACT

Household water treatment with chlorine can improve microbiological quality and reduce diarrhea. Chlorination is typically assessed using free chlorine residual (FCR), with a lower acceptable limit of 0.2 mg/L, however, accurate measurement of FCR is challenging with turbid water. To compare potential measures of adherence to treatment and water quality, we chlorinated recently-collected water in rural Kenyan households and measured total chlorine residual (TCR), FCR, oxidation reduction potential (ORP), and *E. coli* concentration over 72 h in clay and plastic containers. Results showed that 1) ORP served as a useful proxy for chlorination in plastic containers up to 24 h; 2) most stored water samples disinfected by chlorination remained significantly less contaminated than source water for up to 72 h, even in the absence of FCR; 3) TCR may be a useful proxy indicator of microbiologic water quality because it confirms previous chlorination and is associated with a lower risk of *E. coli* contamination compared to untreated source water; and 4) chlorination is more effective in plastic than clay containers presumably because of lower chlorine demand in plastic.

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1. Introduction

Despite substantial gains in access to improved drinking water sources worldwide since the Millennium Development Goals were developed and implemented, an estimated 663 million people still rely on unimproved water sources (UNICEF and WHO, 2015). An additional estimated 1.2 billion people obtain drinking water from improved, but contaminated, water sources. Thus, an estimated 1.8 billion people lack access to safe water (Onda et al., 2013). Consumption of fecally-contaminated drinking water is a leading cause of the approximately 502,000 diarrheal deaths worldwide each year (Pruss-Ustun et al., 2014).

Chlorination is one of the most widely used, practical, and inexpensive forms of household water treatment to quickly inactivate most waterborne disease-causing bacteria and viruses (Rosa and Clasen, 2010). In developing countries, liquid (e.g., sodium hypochlorite solutions) and powdered or solid (e.g., calcium hypochlorite or sodium dichloroisocyanurate) sources of free chlorine are used to disinfect household drinking water and, in a number of studies, chlorination has been shown to reduce the risk of diarrheal disease (Arnold and Colford, 2007; Clasen et al., 2015).

Escherichia coli (E. coli) is used as an indicator of the microbiologic quality of water (Edberg et al., 2000). However, *E. coli* is difficult to measure in the field and other measureable water characteristics can be used as indicators of adherence to water chlorination recommendations, serving as proxies for microbiologic water quality (CDC, 2014; OECD and WHO, 2003; Crump et al., 2004). Following addition of chlorine to water, reactions occur that result in free chlorine species and combined chlorine species; the sum of these two is termed total chlorine. Free chlorine residual (FCR) is the most common measure used because it indicates the most effective species of chlorine for disinfection. Total chlorine residual (TCR) is less frequently used as a water quality measure

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because it also detects combined chlorine species, which are much less effective for disinfection. Oxidation reduction potential (ORP) is another water chemistry parameter increasingly used in water distribution systems (Hall et al., 2007) and swimming pools (Kebabjian, 1995). ORP is a measure of the tendency of oxidants (e.g., chlorine species) to be reduced and it therefore provides an indication of the disinfection capacity of the water.

The World Health Organization (WHO) recommends that FCR in treated water should not fall below 0.2 mg/L (WHO, 2011). For treating water in the home, WHO recommends dosing clear water (<10 Nephelometric Turbidity Units [NTU] turbidity) at 2 mg/L FCR and turbid water (>10 NTU) at 4 mg/L FCR in order to maintain a FCR of 0.2 mg/L for 24 h after treatment (WHO, 2011; Lantagne et al., 2010). Many studies of household water chlorination rely on a combination of self-reported use of chlorine and FCR field tests that utilize N,N-diethly-p-phenylenediamine (DPD) to confirm water treatment. In these studies, discrepancies between reported and confirmed chlorination have been common (Blanton et al., 2010; DuBois et al., 2006; Gupta et al., 2007; Luby et al., 2008). Potential causes of these discrepancies include: 1) reliance on water sources with a high content of organic material that rapidly consumes chlorine (i.e., exerts chlorine demand) (Lantagne, 2008); 2) use of clay pots, which are culturally preferred because they lower water temperature through evaporative cooling, but can exert chlorine demand (Null and Lantagne, 2012; Ogutu et al., 2001); 3) use of wide-mouthed storage containers which facilitate insertion of hands or other objects that could add organic material and decrease FCR (Wright et al., 2004); 4) storage of water for periods exceeding 24 h, a common practice in regions in which water is scarce or water sources are located far from homes, during which time FCR naturally decays (Lantagne, 2008; Briere et al., 2012; Colindres et al., 2008) and; 5) courtesy, or social desirability, bias, in which interviewees provide responses to water treatment questions that they believe interviewers expect, resulting in over-reporting of water treatment (Briere et al., 2012; Luoto et al., 2011).

The “real world” problems of turbidity, proper dosing, type of storage container used, time of storage, and reliance on self-reported water treatment complicate the ability of household water chlorination program staff to evaluate: 1) whether water has been treated and 2) the effectiveness of treatment. Simple methods that are feasible for field use are needed to confirm whether, in the absence of detectable FCR, water was chlorinated and whether this treatment improved water quality. To address these problems, we conducted a household-based study in western Kenya in which we analyzed four measures of water quality at five time points in both clay pots, the most commonly used water storage container (ranging from 62 to 92% of households) (Blanton et al., 2010; Garrett et al., 2008; O'Reilly et al., 2008; Parker et al., 2006), and plastic safe storage containers. In particular, we attempted to determine whether ORP offered advantages over TCR and FCR as confirmatory measures of chlorination, using *E. coli* concentration as the “gold standard” of disinfection effectiveness.

2. Materials and methods

2.1. Study design

To assess changes in water quality over time in a real-world setting and to compare four measures of water quality in two types of water storage containers, we conducted a controlled crossover trial of 2 randomly selected groups of households in western Kenya from August 27-October 19, 2012. In one group (Group A), water was chlorinated and stored in clay pots typically used for drinking water storage; in the other group (Group B), water was chlorinated and stored in a plastic safe storage container (Fig. 1). Over the following 72 h, water quality tests were performed for both groups. After a two-week washout period, the container types were switched between the groups, and the process described above was performed (Fig. 2).

2.2. Study population

We selected a convenience sample of six rural villages in Kisumu County that relied on variety of community drinking water sources and household water storage. Households with the following characteristics were eligible to participate: had ≥ one child <5 years old; collected and transported drinking water in 10 L or 20 L containers (jerry cans or buckets); stored drinking water in a ≥15 L ceramic pots (range 15–30 L) in the home; and were willing to use a plastic safe storage container to store drinking water for half of the study period and their own ceramic pot for the other half of the study. Households that did not store drinking water in ceramic pots with ≥15 L capacity were excluded because of the likelihood that stored water would not last for more than one day.

2.3. Enrollment

In each of the 6 study villages, we obtained a list of all households with at least one child <5 years old from the village chief, or conducted a brief census to obtain the list of households. We then used a random numbers table to select a sample of households with children <5 years old in each of the 6 communities. A total of 60 households were initially enrolled in the study. At the time of enrollment, respondents in households were interviewed about demographic characteristics, and water, sanitation, and hygiene practices. Electronic questionnaires were verbally administered in Dholuo, the local language, by trained Kenyan field research assistants.

2.4. Intervention

The 60 households were randomly allocated to two groups – Groups A (30 households) and B (30 households) (Fig. 2). Group A households were asked to use their clay pots during the first half of the study while Group B households were provided a new, 60 L plastic safe storage container with a lid, tap, and stand.

2.5. Phase 1

Households were contacted in advance and requested to fill their water collection containers (in most cases, 20 L jerry cans) using water from their usual drinking water source on the morning of the first home visit and to keep it in the transport containers. During the first home visit, investigators collected Time 0 (“pre-dose”) water samples by pouring water directly from the transport containers into test vials and sample bottles.

To assess water quality, three water quality and treatment measures were performed using portable field meters in the home. Water samples collected into 10 mL glass vials were tested for TCR (mg/L) and FCR (mg/L) (Hach® Pocket Colorimeter™ II, Loveland, CO, USA); water samples collected into 50-mL polypropylene conical tubes were tested for ORP (mV) (Oakton® Waterproof ORPTestr® 10, Vernon Hills, IL, USA). Additionally, a 100 mL sample was collected in a WhirlPak™ bag containing sodium thiosulfate, stored on ice, and transported to the laboratory within 4–6 h of collection for *E. coli* quantification (CFU/100 mL) using membrane filtration (0.45 μM, 47 mm filters) with m-ColiBlue24® media (Hach®, Loveland, CO, USA). In some cases, because of exceedingly slow filtration rates of water samples due to high turbidity, we limited the volume of filtrate to 20 or 50 mL of sample and