ORIGINAL ARTICLE

Solar disinfection of water for diarrhoeal prevention in southern India

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Aims: To evaluate the efficacy and acceptability of solar irradiation in the prevention of diarrhoeal morbidity in children under 5 years of age, in an urban slum in Vellore, Tamil Nadu.

Methods: A total of 100 children were assigned to receive drinking water that had been subjected to solar disinfection in polyethylene terephthalate bottles. One hundred age and sex matched controls were also selected. Both groups were followed by weekly home visits for a period of six months for any diarrhoeal morbidity. At the end of the follow up period, the acceptability of the intervention was assessed by interviews, questionnaires, and focus group discussions.

Results: There was significant reduction in the incidence, duration, and severity of diarrhoea in children receiving solar disinfected water, despite 86% of the children drinking water other than that treated by the intervention. The incidence of diarrhoea in the intervention group was 1.7 per child-year, and among controls 2.7 per child-year, with an incidence rate ratio of 0.64 (95% CI −0.48 to 0.86). The risk of diarrhoea was reduced by 40% by using solar disinfection. In qualitative evaluation of acceptability, most women felt that solar disinfection was a feasible and sustainable method of disinfecting water.

Conclusions: Solar disinfection of water is an inexpensive, effective, and acceptable method of increasing water safety in a resource limited environment, and can significantly decrease diarrhoeal morbidity in children.

The World Health Organisation estimates that diarrhoeal morbidity can be reduced by 32%, when improved water hygiene and sanitation are provided. However, over 40% of the world's 6 billion people have no acceptable means of sanitation and more than 1 billion people draw their water from unsafe sources.[1] At the household level, boiling water for about 10 minutes or the use of certain chlorine compounds available in tablets or solutions is commonly advocated to disinfect drinking water, but the use of these disinfection methods is limited by economic constraints and a lack of acceptability. Boiling, for example, requires about 1 kg of wood per litre of water, which has adverse effects on indoor air quality and is not economically viable for most households in developing countries.[2] Chlorine is being actively promoted as a low cost disinfection technique but is found to have limited usage because it changes the taste of water. In addition, misuse of chlorine compounds poses a safety hazard.[3]

Previous in vitro studies and field trials in Africa have shown that solar radiation reduces the bacterial count of water and decreases diarrhoeal morbidity in children.[4] We have previously shown the contamination of drinking water at source and during storage in an urban setting in southern India.[5] In this study, we evaluated the efficacy and acceptability of solar water disinfection in the laboratory and in children resident in an urban slum over a six month period.

METHODS

Study area

The intervention area was an urban slum in Vellore town. Demographic data of the inhabitants of this area, water supply, and health facilities were available from an earlier survey. Most of the houses in this area (>60%) do not have toilets. There is an open drain running in front of each house, which is used to dispose of solid and liquid household wastes, as well as for defecation by younger children. The major communities are Muslim (47%), Hindu (45%), and Christian (7%), and most belong to the lower socioeconomic strata. The single most common occupation is beedi-work, which is undertaken by all family members. Most mothers have 2–3 children and live in extended or joint families.

Water supply

The water supply to this area is from two sources, bore wells which provide 24 hour water supply and municipal taps which supply water for 1–2 hours at variable intervals of time ranging from alternate days to once in 3–4 weeks. The municipal supply is used for drinking water, while the bore well water is used for bathing and cleaning. In all seasons, there is a shortage of drinking water, and water is stored in households in a number of containers, mainly wide mouthed metal or plastic containers, with a capacity of 10–12 litres.

Study children and recruitment

A list of houses with children under 5 years of age was obtained from a previous census of the area. From 689 children, 100 study children and 100 age and sex matched controls were selected by simple random sampling of the listed children. No household had more than one child included in the study or as a control. The inclusion criteria were children resident in Ramanaickapalayam, aged between 6 and 59 months, with no history of chronic diarrhoea, from families not using water treatment methods.

Informed consent was obtained from the mothers, who were taught about solar disinfection of water and given water bottles for the use of the study child. They also received health education on the causes and complications of diarrhoea, home based oral rehydration therapy, and methods of preventing diarrhoea. Control children, who did not receive plastic bottles for solar disinfection of water, were also similarly recruited. A nutritional assessment of both study and control children was carried out using Indian Academy of Pediatrics standards.[6]

Solar disinfection method

Each household with a recruited study child was given twelve 1-litre polyethylene terephthalate bottles, sold in the local market, which had one vertical half painted black. The mother was instructed to fill six bottles with water and place them with the clear side on top and the black painted surface below, in a pre-selected position which was determined by identification of the location that received the maximum direct sunlight. The bottles remained in position through the day and were used for drinking the next day. Mothers were instructed not to transfer the water to other containers.

Follow up

The period of follow up was from February to August 2002. Follow up visits were conducted by three field workers, under the supervision of a doctor. At each visit, compliance with the solar disinfection methods and incidence of diarrhoea in the study or control child were recorded. A diagnosis of diarrhoea was made if there was passage of three or more loose or watery stools in a 24 hour period. Agreement between the field workers and the supervising doctor was tested at the beginning and at the end of the study, by the doctor paying an unscheduled visit to 20 randomly selected houses one day after the field worker's visit.

Compliance was measured by observing the water bottles being disinfected and was recorded as the percentage of visits during which the water bottles were found in the correct position.

Determination of acceptability

Acceptability was determined by three qualitative methods, focus group discussions, in-depth interviews, and administration of a questionnaire to record practices and opinions. Two focus group discussions were held among 18 mothers who had children enrolled in the study; these assessed ease of use, financial implications, mechanism of action, and limitations of solar disinfection. Ten mothers were selected for in-depth interviews, and were interviewed repeatedly by the study doctor about their perspectives and experiences with drinking water safety, diarrhoeal disease, and solar disinfection. The practice and opinion questionnaire was administered to all study family and assessed their practice and knowledge of the solar disinfection method at the end of the study follow up period.

Data analysis

The data collected during six months of follow up was entered using EpiInfo and analysed using SPSS version 9.0.

The study protocol was approved by the institutional ethics committee of the Christian Medical College, Vellore.

RESULTS

Water supply

A total of 10 samples of drinking water were analysed for microbiological contamination within two hours after collection from the source. All samples had a confirmed faecal coliform count of >180 *E coli*/100 ml.

Baseline data on study and control children

Table 1 shows the distribution of children according to age. The mean age in months was 27.5 months (SD 13.1) for the study intervention group and 27.3 months (SD 13.1) for the control group. Using the χ^2 test, the two groups were similar in age distribution (p = 0.75), nutritional status (p = 0.868), maternal education (p = 0.614), and socioeconomic status (p = 0.858).

Table 1 Age distribution of the children in study and control group

Age in months	Study group n	Control group n	Total
6–11	10	10	20
12–23	32	32	64
24–35	19	26	45
36–47	27	21	48
48–59	12	11	23
Total	100	100	200

Follow up

During the study period of six months, seven families shifted their residence. Three families moved within the study area, and continued to remain in the study. The other four were lost to follow up. However, the time they contributed to the study was included in the analysis. Three households started boiling their water during the study, and were hence excluded from analysis.

Compliance with use of solar disinfection was good, with 78% of the families recording compliance on >75% of the visits. Only eight families were found to be using the bottles appropriately on less than half the visits. The validity check to analyse agreement between field worker and doctor had a kappa value of 100%, with 6 of 6 reports of diarrhoea, and 14 children without diarrhoea accurately recorded by the field workers.

Diarrhoeal morbidity

A total of 53 children in the intervention study group and 75 controls developed diarrhoea during the six month period of follow up (table 2). This difference is statistically significant (p = 0.001, χ^2 = 10.5). The mean number of episodes was also significantly higher in the controls (*t* test for equality of means, p = 0.001). The mean duration of each episode and the mean number of diarrhoeal stools per episode were also significantly higher in the controls (*t* test for equality of means, p = 0.001). The control group also required more intervention, in terms of needing intravenous rehydration in 34% of episodes, while the study group required intravenous rehydration in 14% of episodes (χ^2 = 3.68, p = 0.05).

Analysing the data as incidence rates of all diarrhoeal illness, the incidence of diarrhoea among the intervention group was 1.7, and among controls was 2.7 per child-year. The incidence rate ratio was 0.64 (95% CI −0.48 to 0.86, p = 0.001). The risk of getting diarrhoea of any severity was reduced by almost 40% by the use of solar disinfected water. The incidence of severe diarrhoea, requiring intravenous rehydration was 0.6 per child-year among the intervention group and 1.3 per child-year in the control group. The incidence rate ratio is 0.45 (95% CI −0.28 to 0.72, p < 0.001). The risk of getting severe diarrhoea is decreased by 50% when the drinking water is disinfected using solar disinfection. The

Table 2 Diarrhoeal morbidity in study and control children during the six month follow up period

	Study group (n = 100)	Control group (n = 100)
Diarrhoea incidence	53	75
Mean number of episodes	1.7	2.9
Mean duration of episodes in days	2.1±2.9	3.6±3.4
Mean number of stools	4.0±4.9	7.8±6.9
Episodes requiring intravenous rehydration	13.9%	34.1%

What is already known on this topic

- Solar irradiation has been experimentally shown to be useful in decontaminating intravenous rehydration solutions and water
- The only field studies in peer reviewed literature are from Maasai children in Kenya with visits every two weeks. The method was shown to reduce diarrhoea, but the reduction was 9% in children aged 5–16 years and 16% in children less than 6 years

What this study adds

- A six month follow up with weekly visits showed a >50% reduction in diarrhoea in children less than 5 years of age
- The reduction in diarrhoea was despite 85% of children consuming other sources of drinking water as well as the disinfected water

preventable fraction of all diarrhoea among the exposed is 0.36 (95% CI 0.14 to 0.52) and that in the population is 0.18. For severe diarrhoea, the preventable fraction among the exposed is 0.55 (95% CI 0.28 to 0.73) and that in the population is 0.28.

Data were not analysed separately for blood and mucous diarrhoea as these data depended on maternal and care giver reports and were not considered reliable based on previous studies.

Determination of acceptability

In the focus group discussions, the women felt that solar disinfection was an easy method of disinfecting water, with none of the inconvenience of boiling, cooling, and storing water. It was considered economical, because the cost of boiling 5 litres of water was estimated to be approximately 68 US cents, although no families were disinfecting because of the cost constraints. They agreed that the sun had the power to kill microorganisms and stated that this was a traditional belief, although water was not customarily kept in bottles. Limitations that were noted in the focus group discussions were that inadequate numbers of bottles were provided, that bottles had a limited life because they cracked, became opaque, or scratched within two months, or were stolen.

In the in-depth interviews, similar information was obtained. One mother discontinued use of the bottles because of a change in the taste and smell of the water. The questionnaire was completed by 88% of the families. Among them, 86% reported that their children were drinking water other than the solar disinfected water (34% more than once a day, 16% once a day, 25% once in 3–4 days, and 11% once a week). Self-reporting of use of solar disinfection was daily in one fifth and over 80% of the time in half the families. Only six families reported that they used solar disinfection less than half of the days of the follow up period.

DISCUSSION

This study provides field and laboratory validation of the use of solar disinfection in decreasing contamination of drinking water and subsequent diarrhoeal morbidity in children. The use of solar irradiation for treatment of contaminated water was documented in 2000 BC.[7] More recently, a number of approaches to the use of solar radiation have found that it removes a wide range of organic chemicals and pathogenic organisms by direct exposure, is relatively inexpensive, economically volume independent, and avoids generation of harmful by-products of chemically driven technologies.[8 9]

This is the first study to assess compliance with solar disinfection in a community setting. It is important to emphasise that in the field evaluation, the solar disinfection method was effective in reducing the number, duration, and severity of diarrhoeal episodes in the children receiving disinfected water (table 2). These differences were statistically significant despite the fact that most children were not using solar disinfected water as their sole source of drinking water. Previous trials in Kenya assessed diarrhoeal morbidity in children below 5, and between 6 and 15 years, receiving solar disinfected water over varying periods of times; they showed a reduction in diarrhoeal episodes and their severity by 16% and 9% respectively.[4 10] In our weekly monitoring, the reduction was over 40%, possibly due, in part, to better recall with intensive follow up.

In the qualitative assessment, the mothers felt that this was a feasible method of disinfecting water because of its low economic requirements. It was also acceptable to most families because the taste and smell were not changed.

The field evaluation of solar disinfection in a natural community setting in southern India showed that the use of the method significantly decreased diarrhoea in children despite not being the sole source of water, and that this is an acceptable and potentially sustainable intervention. Further studies should follow children for at least one complete year and also evaluate the causative organisms in diarrhoea in study and control children in order to determine which enterically transmitted pathogens can be decreased or eliminated by this technique.

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