BRIEF REPORT

A Pilot Study of Solar Water Disinfection in the Wilderness Setting

Christopher M. Tedeschi, MD, MA; Christopher Barsi, MD; Shane E. Peterson, MD; Kevin M. Carey, MD

From the Columbia University College of Physicians and Surgeons, New York, NY; the Long Island Jewish Medical Center, New Hyde Park, NY; the New York Presbyterian Residency Program in Emergency Medicine, New York, NY; and the New York University/Bellevue Hospital Emergency Medicine Residency, New York, NY.

Objective.—Solar disinfection of water has been shown to be an effective treatment method in the developing world, but not specifically in a wilderness or survival setting. The current study sought to evaluate the technique using materials typically available in a wilderness or backcountry environment.

Methods.—Untreated surface water from a stream in rural Costa Rica was disinfected using the solar disinfection (SODIS) method, using both standard containers as well as containers and materials more readily available to a wilderness traveler.

Results.—Posttreatment samples using polyethylene terephthalate (PET) bottles, as well as Nalgene and Platypus water containers, showed similarly decreased levels of *Escherichia coli* and total coliforms.

Conclusions.—The SODIS technique may be applicable in the wilderness setting using tools commonly available in the backcountry. In this limited trial, specific types of containers common in wilderness settings demonstrated similar performance to the standard containers. With further study, solar disinfection in appropriate conditions may be included as a viable treatment option for wilderness water disinfection.

Key words: water microbiology, disinfection, survival

Introduction

Many techniques and devices are available to the wilderness traveler for the safe disinfection of drinking water. Although modalities such as filters, halogenation, and UV light treatment have been well described as safe and effective, other more improvisational techniques may be required in survival settings or when standard methods become unavailable.

Solar disinfection (SODIS) for the treatment of drinking water has been well studied in the microbiology laboratory and is currently in practice as a water purification system in developing nations.^{1,2} The combination of heat and UV light to which the water is

exposed can be sufficient to inactivate the majority of microorganisms in the water, decreasing the risk of enteric illness from waterborne pathogens. The standard method involves at least 6 hours of sun exposure to a polyethylene terephthalate (PET) container filled with no more than 2 to 3 L of water, placed on a black or reflective surface such as a tin roof.³ Purpose-made LDPE (low-density polyethylene) plastic bags, enhanced with reflective aluminum or black plastic bottom surfaces, have been shown to serve as effective reactors as well.⁴ Given its dependence on UV light exposure, SODIS is most effective between the latitudes of 15° N and 35° N (the approximate area between Guatemala City and Santa Barbara, CA) or similarly between 15° S and 35° S (for example, between La Paz, Bolivia, and Buenos Aires, Argentina). The equatorial area between 15° N and 15° S also provides adequate exposure, although the overall intensity of solar radiation in this region is somewhat decreased as a result of increased levels of cloud cover and humidity.⁵ The efficacy of the technique outside of these latitude ranges has not been sufficiently evaluated.

A short description of this work was presented in an abstract poster presentation at the 2013 ACEP Research Forum (Seattle, WA) in October 2013.

Offprints will not be available from the author.

Corresponding author: Christopher Tedeschi, MD, Emergency Medicine Department, Columbia University Medical Center, 622 West 168th Street, VC2, Suite 260, New York, NY 10032. (e-mail: ct2122@columbia.edu).

Field trials have shown the technique to reduce levels of bacterial, viral, and protozoan pathogens to acceptable levels for drinking water, as well as a reduction in the burden of diarrheal disease in communities adopting the practice.³ Proper use of the technique has also been shown to reduce the risk of contracting cholera.⁶

SODIS has obvious potential advantages in austere environments in which individuals may have access to plastic water storage bottles but no filters or reagents necessary for other methods of disinfection, and has been suggested as a viable technique for water treatment in wilderness medicine texts and practice guidelines.⁷ Yet although the materials necessary to properly disinfect water as described (ie, PET bottles, a tin roof or black surface) may be available in a setting such as a remote village, field hospital, or refugee camp, the wilderness traveler may have different materials at hand. Few trials have evaluated the suitability of the SODIS process in a wilderness or survival setting, and descriptions of the technique in standard wilderness medicine texts offer little detail or specifics necessary for successful implementation. We sought to evaluate whether the SODIS technique can be applied using materials and water containers typically available to backcountry travelers.

Recent studies suggest that solar disinfection may work more efficiently when using containers that transmit larger proportions of UV-B. PET, however, transmits very little UV-B, and Tritan copolyester—a proprietary formulation that is the main component of Nalgene water bottles—similarly absorbs the majority of UV-B light.^{3,8} Nonetheless, PET plastic transmits 85% to 90% of UV-A, which is most likely responsible for the antimicrobial effect observed with the technique.³ In one transmittance study, Tritan transmitted slightly greater amounts of UV-A than PET throughout the 320- to 400-nm range.⁸

Fisher et al⁸ effectively tested the SODIS method on Nalgene bottles using the recommended technique of 6 or more hours of sun exposure on an angled piece of corrugated steel at a latitude of 17.4° S. The average time to achieve a 3-log reduction in wastewater *E. coli* burden was 7.54 hours, compared with 6.82 hours for the standard PET bottle in the same environment, although these differences did not seem to be statistically significant.⁸ These results suggest that the Nalgene bottles would perform similarly to PET bottles in realistic field conditions in different locations and possibly when altering other variables, such as the nature of the reflective surface. Presumably, UV-A transmission in Nalgene bottles was primarily responsible for the disinfecting effect.

The solar exposure time required for treatment is quite variable. An exposure time of 6 hours is generally

recommended, but longer times may be required in overcast skies or with water of greater turbidity. Exposure over 2 consecutive days may be required in covered sky conditions to reach the required cumulative radiation dose.⁹ Comparative trials have shown that bacteria and viruses found in the environment may take longer to deactivate compared with laboratory-cultured test organisms.⁸ Some studies have shown that up to 12 hours may be required to render *Cryptosporidium parvum* cysts ineffective, certainly longer than might be acceptable in a survival situation, in which a cumulative 12-hour sun exposure might not be feasible.³

SODIS would be even more applicable to wilderness travel if exposure times could be shortened. Additives such as hydrogen peroxide and lime juice have been shown to dramatically increase the rate at which some microorganisms are inactivated.¹⁰ Further research into easily available additives could make SODIS purification even more relevant to the needs of the wilderness traveler.

Standards for water disinfection in the wilderness setting differ from those intended for household use or for water treatment projects in the developing world. Backcountry travelers must balance the efficacy of any disinfection technique against the resources consumed, time available, and contact time required with the water in question. Although there is no well-established guideline for the wilderness setting, US Environmental Protection Agency guidelines for the evaluation of water purification devices generally recommend a 3- to 6-log reduction in the number of organisms: 3-log for cysts, 4-log for viruses, and 6-log for bacteria, using standardized test organisms.^{11,12}

Methods

The SODIS technique was evaluated during 2 experimental trials on May 8 and May 9, 2012. Surface water was collected from a stagnant stream in Hacienda Baru, a wildlife preserve near Domincal, Costa Rica, at latitude 9.25° N. The high temperature during that 2-day period was 31°C, and the low 23°C, as per data provided by the Instituto Meteorológico Nacional of Costa Rica via e-mail communication. The test periods consisted of exposure to bright sunlight under a nearly cloudless sky.

Water samples were collected in various containers commonly used by outdoor enthusiasts and available at many outdoor retailers in the United States. We choose to compare clear 32-fl. oz. Nalgene bottles (Nalge Nunc, Rochester, NY) and clear 2-L Platypus (2-L flexible water bottle, Cascade Designs, Seattle WA, see [Figure](#)) bladders as well as standard 20-fl. oz. PET water bottles (purchased locally). Nalgene bottles are made from

Figure. From left to right, polyethylene terephthalate, Platypus, and Nalgene bottles placed on a reflective tarp and exposed to sun during trial of backcountry solar disinfection.

patented Tritan copolyester. Platypus bladders are made of a nylon/polyethylene film. Water from a single location in the stream was placed into the 3 different types of containers: Nalgene bottles, PET bottles, and Platypus bladders.

In accordance with published SODIS technique, each water container was filled two-thirds to three-quarters full and aerated by shaking for at least 20 seconds.⁵ The aerated containers were then filled to capacity. All bottles were placed horizontally on a reflective backpacker's survival tarp (Space brand all-weather blanket, Grabber products, Grand Rapids MI; [Figure](#)). The containers were exposed to direct sunlight continuously for 6 hours in each of the trials, as described in the standard user's guide for the SODIS technique.⁵ Control containers were placed in a cool, dark room (CDR) location during the experimental exposure times.

To establish a baseline bacterial load, 1-mL samples were collected from each container using sterile plastic pipettes. 3M Petrifilm *E. coli*/Coliform Count Plates (3M, St. Paul, MN) were inoculated with the samples and incubated for 24 hours at 35°C and 50% humidity, as per manufacturer's recommendations. The total number of bacteria per milliliter of surface water were calculated. At the end of the exposure period, 1-mL samples of water were taken from each of the SODIS containers and tested as described above. None of the samples were treated with any other purification method. Colony-forming units (CFUs) were then counted with the aid of a digital camera with a 4× optical zoom.

E. coli and total coliform colonies were counted after 24 hours of growth. Total preexposure and postexposure bacterial colony counts for the 2 single-day trials are shown in [Table 1](#).

Results

The mean number of *E. coli* CFUs/mL in Nalgene bottles was reduced from a mean of 42 to 35 after exposure to a CDR in trial 1, and from 9 to 6 in trial 2. Mean CFUs/mL of *E. coli* in Nalgene bottles undergoing SODIS exposure was reduced from 36.5 to 0 in trial 1 and from 10.5 to 0 in trial 2. The mean number of total coliform CFUs/mL in Nalgene bottles in CDR was reduced from 66 to 59 in trial 1 and from 41 to 38 in trial 2, and with SODIS treatment, from 65 to 0 in trial 1 and from 47 to 0 in trial 2.

The mean number of *E. coli* CFUs/mL in PET bottles was reduced from a mean of 49 to 37 after exposure to CDR in trial 1, and from 7 to 6 in trial 2. Mean CFUs/mL of *E. coli* in PET bottles undergoing SODIS exposure was reduced from 34 to 0 in trial 1 and from 5.3 to 0 in trial 2. The mean number of total coliform CFUs/mL in PET bottles in CDR was reduced from 80 to 67 in trial 1 and from 58 to 36 in trial 2, and with SODIS treatment, from 61.7 to 0 in trial 1 and from 53.3 to 0 in trial 2.

The mean number of *E. coli* CFUs/mL in Platypus bottles was reduced from a mean of 35 to 32 after exposure to CDR in trial 1, and from 6 to 2 in trial 2. Mean CFUs/mL of *E. coli* in Platypus bottles undergoing SODIS exposure was reduced from 38 to 0 in trial 1 and from 6 to 0.5 in trial 2. The mean number of total coliform CFUs/mL in Platypus bottles in CDR was reduced from 67 to 63 in trial 1 and from 39 to 22 in trial 2, and with SODIS treatment, from 63 to 0 in trial 1 and from 40 to 0.5 in trial 2.

Logarithmic reductions for the above trials are shown in [Table 2](#).

The number of *E. coli* found in the source water on the first trial was greater than on the second. In each case, the total coliform count was significantly reduced after application of the backcountry SODIS technique.

Discussion

Although the SODIS technique has been described as a potentially useful water disinfection technique for backcountry travelers in wilderness texts,⁷ few tests of the method have been done using the actual resources and tools that may be available to a wilderness traveler in a remote location or survival situation. In our experiment we tested the technique in a setting applicable to the wilderness traveler: with commercial water bottles common to outdoor travelers rather than well tested or specially designed PET bottles, and using a survival tarp as a reflective surface rather than a roof or purpose-made black surface as specified in the established method.

Table 1. Total colony counts before and after treatment with SODIS technique

		Preexposure (colonies/mL at 24 h)		Postexposure (colonies/mL at 24 h)	
		<i>E. coli</i> (mean)	Total coliform (mean)	<i>E. coli</i> (mean)	Total coliform (mean)
Trial 1	Nalgene bottle ^a				
	Control: cool/dark room (1 bottle)	42	66	35	59
	Treatment: SODIS (2 bottles)	36.5	65	0	0
	PET bottle ^b				
	Control: cool/dark room (1 bottle)	49	80	37	67
	Treatment: SODIS (3 bottles)	34	61.7	0	0
Trial 2	Platypus bladder ^c				
	Control: cool/dark room (1 bottle)	35	67	32	63
	Treatment: SODIS (2 bottles)	38	63	0	0
	Nalgene bottle ^a				
	Control: cool/dark room (1 bottle)	9	41	6	38
	Treatment: SODIS (2 bottles)	10.5	47	0	0
	PET bottle ^b				
	Control: cool/dark room (1 bottle)	7	58	6	36
	Treatment: SODIS (3 bottles)	5.3	53.3	0	0
	Platypus bladder ^c				
	Control: cool/dark room (1 bottle)	6	39	2	22
	Treatment: SODIS (2 bottles)	6	40	0.5	0.5

SODIS, solar disinfection.

^a Nalgene bottle: polyethylene, wide mouth, clear body, black top, 32 oz.

^b PET bottle: polyethylene terephthalate, narrow mouth, clear body, white top, 20 oz.

^c Platypus bladder: clear body, flexible, 70 oz.

The backcountry SODIS technique significantly lowered the coliform counts in both Nalgene and Platypus containers, and in each case, bacterial counts were reduced to negligible levels. The decrease in bacterial load in each of the 2 experimental containers was similar to the results found in the PET bottles.

LIMITATIONS

Because of logistic constraints, sample sizes were small. A common standard in assessing the efficacy of a water disinfection process is the ability to accomplish a 3- to 6-log reduction in the number of microorganisms present.¹¹ Our sample sizes were not sufficiently large to demonstrate this degree of reduction in either the PET bottles or the experimental bottles. Because of the relatively minor level of contamination in our test water source, we were unable to demonstrate that the SODIS technique was sufficient to treat water to the level of established standards (ie, 6-log reduction for

bacteria); however, we do show that the technique applied in this particular source was essentially equivalent in standard containers when compared with containers commonly carried by wilderness travelers.

Post-SODIS treatment water had a decreased total coliform count as described above, and in almost all cases, no detectable coliform bacteria in the post-SODIS treatment samples. A larger scale study of solar disinfection in a backcountry setting would be required to demonstrate the usefulness of the technique in a variety of circumstances.

We were also unable to test for reductions in other pathogenic microorganisms, such as viruses, *Cryptosporidium*, and *Giardia*, although the SODIS method has been shown effective in controlling these organisms in standard conditions, albeit with longer exposure times for *Cryptosporidium*.¹³

Scratched or tinted bottles reduce SODIS efficiency. Our bottles were purchased new; older containers may contain more scratches and surface irregularities that would make the technique less effective.

Table 2. Logarithmic reduction in colony counts using solar disinfection and control for 3 types of containers

		Logarithmic reduction ^a	
		<i>E. coli</i>	total coliform
Trial 1	Nalgene bottle ^b		
	Control: cool/dark room (1 bottle)	0.08	0.05
	Treatment: SODIS (2 bottles)	1.87	1.82
	PET bottle ^c		
	Control: cool/dark room (1 bottle)	0.12	0.08
	Treatment: SODIS (3 bottles)	1.84	1.80
	Platypus bladder ^d		
	Control: cool/dark room (1 bottle)	0.04	0.03
	Treatment: SODIS (2 bottles)	1.84	1.81
Trial 2	Nalgene bottle ^b		
	Control: cool/dark room (1 bottle)	0.16	0.03
	Treatment: SODIS (2 bottles)	1.34	1.68
	PET bottle ^c		
	Control: cool/dark room (1 bottle)	0.06	0.20
	Treatment: SODIS (3 bottles)	1.07	1.73
	Platypus bladder ^d		
	Control: cool/dark room (1 bottle)	0.41	0.24
	Treatment: SODIS (2 bottles)	0.81	1.44

SODIS, solar disinfection.

^a In calculating log reductions, 0.5 colonies were added to each individual observation to avoid calculating the log of a null set.

^b Nalgene bottle: polyethylene, wide mouth, clear body, black top, 32 oz.

^c PET bottle: polyethylene terephthalate, narrow mouth, clear body, white top, 20 oz.

^d Platypus bladder: clear body, flexible, 70 oz.

Conclusions

Solar disinfection has been shown to be an effective and practical method of drinking water disinfection in the developing world and in limited-resource settings. Our pilot study suggests that the technique may be equally applicable to the wilderness traveler or in survival situations in tropical settings, using commonly available materials. Larger scale, quantitative studies using similar materials could potentially demonstrate that solar disinfection should be added to the repertoire of techniques available to wilderness travelers. Further study in the backcountry setting could yield specific recommendations regarding materials, geography, solar contact time and appropriate containers for using the technique successfully, thus enabling wilderness instructors and textbooks to relay information with accuracy and specificity.

The current study also helps to demonstrate the potentially fruitful intersection between the worlds of

wilderness medicine and global health practice, in which improvisation and smart resource allocation play key roles in clinical practice. In recent years, considerable overlap has developed between the tools and techniques of wilderness medicine and the worlds of disaster medicine and humanitarian relief. In this paper, we consider a technique originally developed in the context of water purification in resource-poor settings, namely the developing world, and attempt to demonstrate its effectiveness in a survival or backcountry setting, using tools generally available to a wilderness traveler.

Acknowledgments

The authors thank the faculty and students of Cornell Wilderness Medicine, who supported and assisted research efforts during an expedition to Costa Rica. Our project would not have been possible without the logistic support of Cornell Outdoor Education,

specifically Todd Miner, EdD, Michael Vortmann, MD, and Jane Kim, MD.

References

1. Berney M, Weilenmann HU, Simonetti A, Egli T. Efficacy of solar disinfection of *Escherichia coli*, *Shigella flexneri*, *Salmonella* Typhimurium and *Vibrio cholerae*. *J Appl Microbiol*. 2006;101:828–836.
2. du Preez M, Conroy RM, Ligondo S, et al. Randomized intervention study of solar disinfection of drinking water in the prevention of dysentery in Kenyan children aged under 5 years. *Environ Sci Technol*. 2011;45:9315–9323.
3. McGuigan KG, Conroy RM, Mosler HJ, du Preez M, Ubomba-Jaswa E, Fernandez-Ibañez P. Solar water disinfection (SODIS): a review from bench-top to roof-top. *J Hazard Mater*. 2012;235–236:29–46.
4. Dunlop PS, Ciavola M, Rizzo L, Byrne JA. Inactivation and injury assessment of *Escherichia coli* during solar and photocatalytic disinfection in LDPE bags. *Chemosphere*. 2011;85:1160–1166.
5. Meierhofer R, Wegelin M. Solar Water Disinfection: A Guide for the Application of SODIS. Dübendorf: Swiss Federal Institute of Environmental Science and Technology. 2002.
6. Conroy RM, Meegan ME, Joyce T, McGuigan K, Barnes J. Solar disinfection of drinking water protects against cholera in children under 6 years of age. *Arch Dis Child*. 2001;85:293–295.
7. Backer HD. Field water disinfection. In: Auerbach PS, ed. *Wilderness Medicine* 6th ed. Philadelphia: Mosby; 2012: 1324–1359.
8. Fisher MB, Iriarte M, Nelson KL. Solar water disinfection (SODIS) of *Escherichia coli*, *Enterococcus* spp., and MS2 coliphage: effects of additives and alternative container materials. *Water Res*. 2012;46:1745–1754.
9. SODIS Technical Note #11: SODIS Efficiency: Covered Sky Conditions. 2011. Available at: . Available at: http://www.sodis.ch/methode/anwendung/factsheets/covered_sky_e.pdf. Accessed January 8, 2014.
10. Fisher MB, Keenan CR, Nelson KL, Voelker BM. Speeding up solar disinfection (SODIS): effects of hydrogen peroxide, temperature, pH, and copper plus ascorbate on the photo-inactivation of *E. coli*. *J Water Health*. 2008;6:35–51.
11. Backer H. Water disinfection for international and wilderness travelers. *Clin Infect Dis*. 2002;34:355–364.
12. US Environmental Protection Agency, Registration Division, Office of Pesticide Program, Criteria and Standards Division, Office of Drinking Water. *Guide Standard and Protocol for Microbiological Water Purifiers (revised)*. April 1987.
13. McGuigan KG, Méndez-Hermida F, Castro-Hermida JA, et al. Batch solar disinfection inactivates oocysts of *Cryptosporidium parvum* and cysts of *Giardia muris* in drinking water. *J Appl Microbiol*. 2006;101:453–463.