Travel Medicine and Infections Disease (2015) 13, 466–474

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevierhealth.com/journals/tmid

Drinking water treatment with ultraviolet light for travelers — Evaluation of a mobile lightweight system

Lisa F. Timmermann[a,*], **Klaus Ritter**[b], **David Hillebrandt**[c], **Thomas Küpper**[a,c]

[a] *Institute of Occupational & Social Medicine, RWTH Aachen University, Aachen, Germany*
[b] *Institute of Medical Microbiology, RWTH Aachen University, Aachen, Germany*
[c] *Medical Commission of the Union Internationale des Associations d'Alpinisme (UIAA MedCom), Bern, Switzerland*

Received 26 August 2015; received in revised form 27 October 2015; accepted 29 October 2015
Available online 6 November 2015

KEYWORDS
Steripen;
UV radiation;
Disinfection;
Waterborne pathogens;
Travelers' diarrhea

Summary
Background: The SteriPEN® is a handheld device for disinfecting water with ultraviolet (UV) radiation. The manufacturer claims a reduction of at least 99.9% of bacteria, viruses, and protozoa. The present study intends to verify the general effectiveness of the device. Furthermore, the influence of bottle geometry and water movement is examined and the issue of user safety with regard to UV-C radiation is addressed.
Methods: The device was applied on water containing a known number of microorganisms (*Escherichia coli*, *Staphylococcus aureus*, and the spore of *Geobacillus stearothermophilus*) and the survival rate was examined. Three different types of bottles commonly used among travelers served as test containers. All tests were conducted with and without agitating the water during irradiation. Furthermore, a spectral analysis was performed on the light of the device.
Results: The SteriPEN® reached a mean reduction of more than 99.99% of bacteria and 99.57% of the spores when applied correctly. However, the results of the trials without agitating the water only yielded a 94.98% germ reduction. The device's maximal radiation intensity lies at 254 nm which is the wavelength most efficient in inactivating bacteria. The UV-C fraction is filtered out completely by common bottle materials. However, when applied in larger containers a portion of the UV-C rays exits the water surface.
Conclusions: If applied according to the instructions the device manages a satisfactory inactivation of bacteria. However, it bears the danger of user errors relevant to health. Therefore, education on the risks of incorrect application should be included in the travel

* Corresponding author. Institute of Occupational and Social Medicine, RWTH Aachen University, University Hospital Aachen, Pauwelsstr. 30, 52074 Aachen, Germany.
E-mail addresses: Lisa.Timmermann@rwth-aachen.de (L.F. Timmermann), kritter@ukaachen.de (K. Ritter), dh@hillebrandt.org.uk (D. Hillebrandt), tkuepper@ukaachen.de (T. Küpper).

http://dx.doi.org/10.1016/j.tmaid.2015.10.005

medical consultation. Also there are still aspects that need to be subject to further independent research.

1. Introduction

Drinking water hygiene is one of the major topics in a travel medical consultation before visiting countries with poor hygienic conditions. For the prevention of travelers' diarrhea and other diseases transmitted by waterborne pathogens travelers are advised to choose an adequate method for personally treating the local water [1,2]. Among the well-established techniques for drinking water disinfection are chemical (e.g. chlorine, iodine) and physical methods (e.g. boiling, filtration) [3].

A relatively recent development on the market for personal water treatment equipment is the SteriPEN®. It is a handheld battery-powered device for disinfecting water by means of ultraviolet (UV) radiation, marketed by its manufacturer Hydro-Photon Inc. since 1999 (Fig. 1). While in the first years the SteriPEN® was not very widely spread it nowadays enjoys increasing popularity among travelers in regions where there is limited access to clean drinking water. A questionnaire based study conducted 2011 in the Everest region, Nepal, showed that the SteriPEN® was just as frequently used as ceramic filters and iodine drops/tablets, each method represented with around 7% of the participants (compared to around 33% chlorine, 24% boiling, 17% bought, and 5% none/other) [4].

The principle of UV-disinfection is not new. It has been used for the treatment of communal water supplies since the middle of the 20th century [5]. Also, methods do exist for using part of the sunlight's UV-fraction to disinfect water stored in PET bottles by placing them on a reflecting surface for several hours ("SODIS") [6].

Figure 1 The SteriPEN® (Photo: L. Timmermann).

The SteriPEN® constitutes the first commercially available UV-application for personal use. Compared to the conventional chemical and physical methods of drinking water disinfection the SteriPEN® has some appealing advantages but also some disadvantages (Table 1).

The SteriPEN® has been tested by several laboratories in the USA and Canada, contracted by the manufacturer, and found to meet the requirements of the U.S. Environmental Protection Agency. Most of these studies work with the MS-2 coliphage, a very UV resistant virus that infects and replicates in the bacterium *E. coli*, as a surrogate for a wide range of waterborne human pathogens. Correct application of the SteriPEN® on one liter of clear water showed a reduction of the coliphage between 99.6806% (log 2.51) [7] and 99.9641% (log 3.45) [8]. This is considered to be equivalent to a reduction of at least 99.9999% of bacteria and 99.99% of viruses [9]. Furthermore, the SteriPEN®'s efficacy has been evaluated against Klebsiella, Cryptosporidium, poliovirus type 1 and rotavirus SA-11 with good results respectively [10-12]. The studies described above are published on the SteriPEN®'s website [13].

However, papers published by independent, peer-reviewed journals are scarce. There currently is no search result on the term "Steripen" in PubMed (October 2015). This gave reason to conduct the present study which intends to verify the general effectiveness of the device. Furthermore, the radiation geometry of the SteriPEN®'s bulb suggests that it might be less effective in slim long bottles with a narrow bottle mouth than in shorter wide-mouthed containers (Fig. 2). Thus, the influence of bottle shape and the importance of water movement during irradiation were investigated. Finally, a spectral analysis was performed on the radiation emitted by the device.

1.1. Functional principle of UV-disinfection

Ultraviolet light is electromagnetic radiation of wavelengths just below the spectrum of visible light (400–780 nm). It is subdivided into three groups: UV-A with a wavelength of 315–400 nm, UV-B with 280–315 nm, and UV-C with 100–280 nm (Fig. 3) [14]. The smaller the wavelength the more energetic is the radiation. Next to its visible spectrum the sun also emits UV light. However, in contrast to the UV-A and -B rays the UV-C fraction is virtually completely absorbed by the atmosphere [14]. This is why microorganisms did not have the opportunity to develop proper mechanisms of resistance against UV-C. Therefore, the part of UV radiation most effective in destroying these organisms is UV-C with a peak of inactivation at 254 nm for bacteria [15].

The damage to microorganisms caused by UV radiation occurs directly on DNA. UV irradiation of the DNA molecule causes thymine bases to form dimers [15,16]. Thus, the