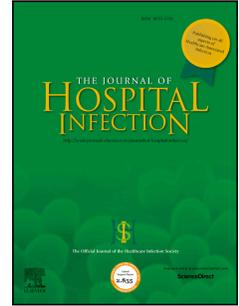


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**Field-testing of a novel color indicator added to chlorine solutions used for decontamination of surfaces in Ebola Treatment Units**

Jason Kang<sup>a</sup>; Kevin S. Tyan<sup>a</sup>; Katherine Jin<sup>a</sup>; Aaron M. Kyle<sup>b</sup>

**Affiliations:**

a. Kinnos Inc., Brooklyn, New York, USA

b. Department of Biomedical Engineering, Columbia University, New York, New York, USA

**Corresponding Author:**

Jason Kang

760 Parkside Avenue, Suite 215, Brooklyn, NY 11226

+1 (978) 314-3127

jason@kinnos.us

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**Summary**

Disinfection with chlorine solution was used in West Africa to prevent transmission of Ebola virus disease. This study surveyed 94 healthcare personnel and community leaders in Liberia and Guinea to assess understanding of disinfection and evaluate feedback on the perceived usefulness of Highlight<sup>®</sup>, a new color indicator designed to improve chlorine disinfection procedures. Using a Likert-type scale questionnaire, respondents agreed or strongly agreed ( $p < 0.0001$ ) that Highlight<sup>®</sup> improved coverage of chlorine solution and feelings of confidence.

## Introduction

The 2014-2015 Ebola virus disease (EVD) outbreak in West Africa resulted in over 11 299 deaths, 513 of which were healthcare personnel (HCP).<sup>1</sup> The high rate of transmission among HCP has underscored the critical need for proper decontamination of personal protective equipment (PPE).<sup>2,3</sup>

Few studies have examined how well local HCPs in West Africa are trained on and adhere to infection prevention guidelines. The most important factors in spray decontamination are full coverage of surfaces and adequate contact time.<sup>4,5</sup> During the EVD outbreak, local HCPs were trained to use 0.5% chlorine solution.<sup>6</sup> A recently developed chemical additive, Highlight<sup>®</sup> (Kinnos Inc., Brooklyn, NY), colorizes chlorine disinfectants to visualize surface coverage, reduces droplet formation and improves adherence of chlorine solution on hard, non-porous surfaces, and the color fades to transparency to indicate when contact time has been met. We traveled to Liberia and Guinea to assess HCPs' knowledge of coverage and contact time, and to evaluate their perception of Highlight<sup>®</sup>.

## Methods

From November 8<sup>th</sup> - November 19<sup>th</sup>, 2015, HCPs (n=53) were surveyed and trained at three locations in Liberia: Project Concern International's Ebola Treatment Unit (ETU), Ganta, Liberia; Karnplay Health Clinic, Karnplay, Liberia; and ELWA3 ETU, Monrovia, Liberia. From May 31<sup>st</sup> - June 13<sup>th</sup>, 2016, HCPs (n=20) were surveyed and trained at two locations in Guinea: International Medical Corps (IMC) Simulation Site, Conakry, Guinea; and Donka Hospital, Conakry, Guinea.

At each site, a "pre-training" survey was orally administered in the HCP's native language. The survey consisted of Likert-type scale questions (1 ~ Strongly Disagree, 5 ~ Strongly Agree). HCPs were asked to demonstrate normal doffing procedures, typically using 0.5% calcium hypochlorite or sodium dichloroisocyanurate via 10 L contractor sprayers (Figure 1, left). They were also asked to spray a rectangular patch of white Tyvek material until they were "satisfied the entire surface was covered." Volume of chlorine solution used and time elapsed, normalized by surface area, were quantified.

HCPs reviewed a two-page pictorial/text-based instruction pamphlet, and prepared Highlight<sup>®</sup>-enhanced chlorine solution. HCPs used this Highlight<sup>®</sup>-enhanced chlorine solution to perform doffing procedures (Figure 1, right) and decontaminate a rectangular patch of white Tyvek material. A final Likert-type scale "post-training" survey was administered. For the two surveys, a two-tailed Wilcoxon signed-rank test with a 95% confidence interval was used to determine if answers were statistically significant compared to a neutral score of 3. An average score greater than 3 with statistical significance would indicate an affirmative response (Agree/Strongly Agree). Finally, with approval from the Guinean Ministry of Health, IMC staff sprayed Highlight<sup>®</sup>-enhanced chlorine solution on various surfaces in front of community leaders (n=21) in Dubreka, Guinea. Binary approvals or disapprovals regarding the cultural sensitivity of coloring surfaces were noted.

## Results

73 total HCPs completed both surveys. In the pre-training survey average responses (Table I), respondents agreed ( $p < 0.0001$ ) that: they felt protected using chlorine solution; chlorine solution fully covers sprayed surfaces; ineffective decontamination is a main cause of infection; they would feel safer if chlorine solution could be better visualized; and chlorine inhalation negatively impacted their health. The respondents were generally neutral that the administered chlorine solution evaporated too quickly ( $p = 0.20$ ). When asked the contact time needed for chlorine solution to fully disinfect EVD, 62% of respondents believed it took 10 or more minutes. 73% of respondents stated that they spray a surface with multiple passes rather than just once, assuming that this would increase efficacy.

In the doffing procedures, two themes emerged. First, although most HCPs recognized the 10 minutes contact time of chlorine solution, HCPs generally doffed their PPE prematurely, with an average time of 5 minutes 26 seconds  $\pm$  28 seconds. Second, HCPs complained of irritation from chlorine inhalation: 57% of respondents reported respiratory distress, headache, and/or vomiting.

In the post-training survey average responses (Table I), all results were found to be statistically significant compared to the neutral response ( $p < 0.0001$ ). HCPs agreed or strongly agreed that Highlight<sup>®</sup>: improved coverage; improved confidence in their safety; was not as irritating as chlorine solution alone; and that they would regularly use Highlight<sup>®</sup>. The average doffing time using Highlight<sup>®</sup> was 7 minutes 16 seconds  $\pm$  25 seconds.

When conducting doffing procedures using Highlight<sup>®</sup>, there were three observations. First, HCPs used a more methodical back-and-forth sweeping motion of spraying, only going over the surface once rather than multiple times with chlorine solution alone. Second, Highlight<sup>®</sup> can be used to confirm a chlorine solution is the correct concentration. In correctly-prepared 0.5% chlorine solution, Highlight<sup>®</sup> remains stably colored in bulk (e.g. in a contractor sprayer) for 5-6 hours and fades in 10 minutes sprayed on a surface. At one ETU, HCPs had previously been told to combine one spoon of calcium hypochlorite powder per liter of water. However, the spoons provided were only half the necessary size. We discovered this error since Highlight<sup>®</sup> did not fade in the correct time in this overly dilute concentration of chlorine. Third, Highlight<sup>®</sup> could be used as a PPE quality-control tool. At another ETU, HCPs' scrubs were colored blue from Highlight<sup>®</sup> that penetrated the gown after doffing, indicating that the PPE at this ETU were not waterproof.

When spraying the patch of Tyvek material with chlorine solution alone, HCPs sprayed a normalized average volume of  $0.20 \pm 0.04$  L/m<sup>2</sup> and took a time of  $28.25 \pm 3.96$  s/m<sup>2</sup>. With Highlight<sup>®</sup>-enhanced chlorine solution, the volume was  $0.17 \pm 0.02$  L/m<sup>2</sup> and the time was  $32.50 \pm 2.67$  s/m<sup>2</sup>. There was no statistically significant difference between the volumes ( $p=0.49$ ) or times ( $p=0.24$ ).

In the cultural sensitivity survey with community leaders in Dubreka, Guinea, 100% of respondents recommended the use of Highlight<sup>®</sup> for surface decontamination.

## Discussion

HCPs were generally aware of appropriate contact times as the response of 10 minutes corresponded to World Health Organization guidelines.<sup>7</sup> Furthermore, the tendency to spray a surface multiple times with chlorine solution indicates a baseline understanding of the need for full coverage. However, there exists a discrepancy between understanding this knowledge and putting it into practice.

Highlight<sup>®</sup> was well-received by HCPs and community leaders. Although Highlight<sup>®</sup> did not immediately change behavior around waiting the full contact times for doffing PPE, HCPs adopted a more methodical technique for spraying and found Highlight<sup>®</sup> to improve coverage and confidence in their safety. Experimental data (unpublished) demonstrates that chlorine solutions alone yield <33% surface coverage across 10 minutes compared to Highlight<sup>®</sup>-enhanced chlorine solutions which maintain >99% surface coverage due to reduced droplet formation and improved adherence.

Notably, Highlight<sup>®</sup> can act as a quality-control check for incorrectly-prepared concentrations of chlorine solution and as a safeguard against using non-compliant PPE. There was no statistically significant difference in the volume or time between using chlorine solution alone or Highlight<sup>®</sup>-enhanced chlorine solution, suggesting that Highlight<sup>®</sup> could be integrated into existing decontamination protocols.

Spraying chlorine solution for decontamination has been associated with respiratory irritation due to aerosolization of the solution.<sup>8</sup> We note that the HCPs surveyed agreed that Highlight<sup>®</sup> reduced the smell and irritation of chlorine ( $p < 0.0001$ ), mitigating their reluctance to use chlorine solution. This is due to an agent in Highlight<sup>®</sup> designed to increase spray droplet size, reduce bounce-back, and limit aerosolization.

The utility of Highlight<sup>®</sup> could be extended beyond the Ebola outbreak for routine decontamination in hospitals and in the field during other disease outbreaks, as well as for biosafety training in laboratories and hospitals. A recent study demonstrates that Highlight<sup>®</sup> does not reduce the efficacy of chlorine solution when used on *C. difficile* spores and improves HCP ability to correctly identify where chlorine solution has been applied on a variety of common healthcare surfaces.<sup>9</sup>

**Conclusion**

More training is recommended for HCPs, specifically around coverage and contact times of disinfectants. Highlight<sup>®</sup> can serve a real-time training tool to enhance compliance. Further studies on the ability for Highlight<sup>®</sup> to improve chlorine decontamination protocol adherence are warranted.

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**Potential conflicts of interest**

J.K., K.S.T., and K.J. are founders and shareholders of Kinno Inc. and have patents pending on the Highlight<sup>®</sup> technology. A.M.K. declares no conflicts of interest relevant to this article.

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## Tables

Table I. Pre-Training Survey to Assess Baseline Knowledge of Disinfection and Post-Training Survey to Evaluate Feedback of Highlight®

Question	Average Score	Standard Error	p-value
<b>PRE-TRAINING SURVEY (n=73)</b>			
I feel protected using chlorine for disinfection	4.27	0.10	<0.0001
Chlorine fully covers surfaces when sprayed	3.84	0.13	<0.0001
It is easy to spray chlorine onto surfaces	4.12	0.12	<0.0001
I can see exactly where I've sprayed using chlorine	3.68	0.14	<0.0001
Chlorine evaporates too quickly	2.77	0.15	0.20
I have been harmed by the smell of chlorine	3.95	0.13	<0.0001
Improper disinfection with chlorine is one of the main reasons people get infected with Ebola	4.37	0.13	<0.0001
Disinfection would be easier if I can see where I sprayed	4.59	0.10	<0.0001
I will feel more protected if I can see where I sprayed	4.62	0.09	<0.0001
<b>POST-TRAINING SURVEY (n=73)</b>			
The directions on how to use Highlight are clear	4.78	0.05	<0.0001
Mixing Highlight into the chlorine was easy	4.78	0.06	<0.0001
It was easy to spray Highlight onto surfaces	4.87	0.04	<0.0001
The blue color of Highlight made it easier to see the sprayed surfaces	4.94	0.03	<0.0001
Compared to chlorine alone, Highlight did a better job of fully covering the sprayed surfaces	4.69	0.07	<0.0001
Compared to chlorine alone, Highlight made me feel safer and more confident about decontamination	4.84	0.16	<0.0001
Highlight released less chlorine smell	4.46	0.10	<0.0001
I would regularly use Highlight for daily decontamination in the future	4.74	0.05	<0.0001
I would prefer to use Highlight over the current method	4.79	0.10	<0.0001
I would recommend Highlight to be used in the next epidemic outbreak	4.95	0.05	<0.0001

## Figures



Figure 1

Figure 1. HCPs conduct spray decontamination doffing procedures with chlorine solution alone (left) and with Highlight<sup>®</sup>-enhanced chlorine solution (right) in Conakry, Guinea.