

1 Far-UVC light: A new tool to control the spread of airborne-mediated microbial  
2 diseases

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10

11 **Abstract**

12 Airborne-mediated microbial diseases such as influenza and tuberculosis represent major public  
13 health challenges. A direct approach to prevent airborne transmission is inactivation of airborne  
14 pathogens, and the airborne antimicrobial potential of UVC ultraviolet light has long been established;  
15 however, its widespread use in public settings is limited because conventional UVC light sources are  
16 both carcinogenic and cataractogenic. By contrast, we have previously shown that far-UVC light (207-  
17 222 nm) efficiently kills bacteria without harm to exposed mammalian skin. This is because, due to its  
18 strong absorbance in biological materials, far-UVC light cannot penetrate even the outer (non living)  
19 layers of human skin or eye; however, because bacteria and viruses are of micrometer or smaller  
20 dimensions, far-UVC can penetrate and inactivate them. We show for the first time that far-UVC

21 efficiently kills airborne aerosolized viruses, a very low dose of 2 mJ/cm<sup>2</sup> of 222-nm light inactivating  
22 >95% of aerosolized H1N1 influenza virus. Continuous very low dose-rate far-UVC light in indoor  
23 public locations is a promising, safe and inexpensive tool to reduce the spread of airborne-mediated  
24 microbial diseases.

25

26 Airborne-mediated microbial diseases represent one of the major challenges to worldwide public  
27 health<sup>1</sup>. Common examples are influenza<sup>2</sup>, appearing in seasonal<sup>3</sup> and pandemic<sup>4</sup> forms, and bacterially-  
28 based airborne-mediated diseases such as tuberculosis<sup>5</sup>, increasingly emerging in multi-drug resistant  
29 form.

30 A direct approach to prevent the transmission of airborne-mediated disease is inactivation of the  
31 corresponding airborne pathogens, and in fact the airborne antimicrobial efficacy of ultraviolet (UV)  
32 light has long been established<sup>6-8</sup>. Germicidal UV light can also efficiently kill both drug-sensitive and  
33 multi-drug-resistant bacteria<sup>9</sup>, as well differing strains of viruses<sup>10</sup>. However, the widespread use of  
34 germicidal ultraviolet light in public settings has been very limited because conventional UVC light  
35 sources are a human health hazard, being both carcinogenic and cataractogenic<sup>11,12</sup>.

36 By contrast, we have earlier shown that far-UVC light generated by filtered excimer lamps  
37 emitting in the 207 to 222 nm wavelength range, efficiently kills drug-resistant bacteria, without  
38 apparent harm to exposed mammalian skin<sup>13-15</sup>. The biophysical reason is that, due to its strong  
39 absorbance in biological materials, far-UVC light does not have sufficient range to penetrate through  
40 even the outer layer (stratum corneum) on the surface of human skin, nor the outer tear layer on the  
41 outer surface of the eye, neither of which contain living cells; however, because bacteria and viruses are  
42 typically of micron or smaller dimensions, far-UVC light can still efficiently traverse and inactivate  
43 them<sup>13-15</sup>.

44 The earlier studies on the germicidal efficacy of far UVC light<sup>13,15-18</sup> were performed exposing  
45 bacteria irradiated on a surface or in suspension. In that a major pathway for the spread of influenza A is  
46 aerosol transmission<sup>3</sup>, we investigate for the first time the efficacy of far-UVC 222-nm light for  
47 inactivating airborne viruses carried by aerosols – with the goal of providing a potentially safe  
48 alternative to conventional 254-nm germicidal lamps to inactivate airborne microbes.

## 49 Results

50 **Virus inactivation.** Fig. 1 shows representative fluorescent 40x images of mammalian epithelial cells  
51 incubated with airborne viruses that had been exposed in aerosolized form to far-UVC doses (0, 0.8, 1.3  
52 or 2.0 mJ/cm<sup>2</sup> ) generated by filtered 222-nm excimer lamps. Blue fluorescence was used to identify the  
53 total number of cells in a particular field of view, while green fluorescence indicated the integration of  
54 live influenza A (H1N1) viruses into the cells. Results from the zero-dose control studies (Fig. 1, top  
55 left) confirmed that the aerosol irradiation chamber efficiently transmitting the aerosolized viruses  
56 through the system, after which the live virus efficiently infected the test mammalian epithelial cells.

57 Fig. 2 shows the surviving fraction, as a function of the incident 222-nm far-UVC dose, of  
58 exposed H1N1 aerosolized viruses, as measured by the number of focus forming units in incubated  
59 epithelial cells relative to unexposed controls. Linear regressions (see below) showed that the survival  
60 results followed a classical exponential UV disinfection model with rate constant  $k=1.8$  cm<sup>2</sup>/mJ (95%  
61 confidence intervals 1.5-2.1 cm<sup>2</sup>/mJ). The overall model fit was good, with a coefficient of  
62 determination,  $R^2= 0.95$ , which suggests that most of the variability in virus survival was explained by  
63 the exponential model. The rate constant of 1.8 cm<sup>2</sup>/mJ corresponds to an inactivation cross-section  
64 (dose required to kill 95% of the exposed viruses) of  $D_{95} = 1.6$  mJ/cm<sup>2</sup> (95% confidence intervals 1.4-1.9  
65 mJ/cm<sup>2</sup>).

66

## 67 Discussion

68 We have developed an approach to UV-based sterilization using single-wavelength far-UVC  
69 light generated by filtered excilamps, which selectively inactivate microorganisms, but does not produce  
70 biological damage to exposed mammalian cells and tissues<sup>13-15</sup>. The approach is based on biophysical

71 principles in that far-UVC light can traverse and therefore kill bacteria and viruses which are typically  
72 micrometer dimensions or smaller, whereas due to its strong absorbance in biological materials, far-  
73 UVC light cannot penetrate even the outer dead-cell layers of human skin, nor the outer tear layer on the  
74 surface of the eye.

75 Here we applied this approach to test the efficacy of the 222-nm far-UVC light to kill influenza  
76 A virus (H1N1) carried by aerosols in a benchtop aerosol UV irradiation chamber, which generated  
77 aerosol droplets of sizes similar to those generated by human coughing and breathing. Aerosolized  
78 viruses flowing through the irradiation chamber were exposed to UVC emitting lamps placed in front of  
79 the chamber window.

80 As shown in Fig. 2, killing of influenza A virus (H1N1) by 222-nm far-UVC light follows a  
81 typical exponential disinfection model, with an inactivation cross-section of  $D_{95} = 1.6 \text{ mJ/cm}^2$  (95% CI:  
82 1.4-1.9). For comparison, using a similar experimental arrangement, but using a conventional 254 nm  
83 germicidal UVC lamp, McDevitt *et al.*<sup>19</sup> found a  $D_{95}$  value of  $1.1 \text{ mJ/cm}^2$  (95% CI: 1.0-1.2) for H1N1  
84 virus. Thus as we<sup>13,15</sup> and others<sup>16-18</sup> reported in earlier studies for bacterial inactivation, 222-nm far-  
85 UVC light and 254-nm broad-spectrum germicidal light are quite similar in their efficiencies for viral  
86 inactivation, the comparatively small differences presumably reflecting differences in nucleic acid  
87 absorbance. However as discussed above, based on biophysical considerations and in contrast to the  
88 known human health safety issues associated with conventional germicidal 254-nm broad-spectrum  
89 UVC light, far-UVC light does not appear to be cytotoxic to exposed human cells and tissues *in vitro* or  
90 *in vivo*<sup>13-15</sup>.

91 If these results are confirmed in other scenarios, it follows that the use of overhead low-level far-  
92 UVC light in public locations may represent a safe and efficient methodology for limiting the  
93 transmission and spread of airborne-mediated microbial diseases such as influenza and tuberculosis. In

94 fact the potential use of ultraviolet light for airborne disinfection is by no means new, and was first  
95 demonstrated more than 80 years ago<sup>8,20</sup>. As applied more recently, airborne ultraviolet germicidal  
96 irradiation (UVGI) utilizes conventional germicidal UVC light in the upper part of the room, with  
97 louvers to prevent direct exposure of potentially occupied room areas<sup>21</sup>. This results in blocking more  
98 than 95% of the UV radiation exiting the UVGI fixture, with substantial decrease in effectiveness<sup>22</sup>. By  
99 contrast, use of low-level far-UVC fixtures, which are potentially safe for human exposure, could  
100 provide the desired antimicrobial benefits without the accompanying human health concerns of  
101 conventional germicidal lamp UVGI.

102 A key advantage of the UVC based approach, which is in clear contrast to vaccination  
103 approaches, is that UVC light is likely to be effective against all airborne microbes. For example, while  
104 there will almost certainly be variations in UVC inactivation efficiency as different influenza strains  
105 appear, they are unlikely to be large<sup>7,10</sup>. Likewise, as multi-drug-resistant variants of bacteria emerge,  
106 their UVC inactivation efficiencies are also unlikely to change greatly<sup>9</sup>.

107 Finally it is of course by no means the case that all microbes are harmful, and it is well  
108 established that the human microbiome is essential to human health<sup>23</sup>. With the exception of a subset of  
109 the skin microbiome, all the human microbiome would be entirely shielded from far-UVC light due to  
110 its very short range; in fact even within the skin biome only those biota on the skin surface<sup>24</sup> would be  
111 potentially affected, which are of course the same biota that are potentially removed by hand  
112 sanitizers<sup>25</sup>.

113 In conclusion, we have shown for the first time that very low doses of far-UVC light efficiently  
114 kill airborne viruses carried by aerosols. For example, a very low dose of 2 mJ/cm<sup>2</sup> of 222-nm light  
115 inactivates >95% of airborne H1N1 virus. Our results indicate that far-UVC light is a powerful and  
116 inexpensive approach for prevention and reduction of airborne viral infections without the human health

117 hazards inherent with conventional germicidal UVC lamps. If these results are confirmed in other  
118 scenarios, it follows that the use of overhead very low level far-UVC light in public locations may  
119 represent a safe and efficient methodology for limiting the transmission and spread of airborne-mediated  
120 microbial diseases. Public locations such as hospitals, doctors' offices, schools, airports and airplanes  
121 might be considered here. This approach may help limit seasonal influenza epidemics, transmission of  
122 tuberculosis, as well as major pandemics.

123

## 124 **Methods**

125 **Far-UVC lamps.** We used a bank of three excimer lamps containing a Kr-Cl gas mixture that  
126 predominantly emits at 222 nm<sup>26,27</sup>. The exit window of each lamp was covered with a custom bandpass  
127 filter designed to remove all but the dominant emission wavelength as previously described<sup>15</sup>. Each  
128 bandpass filter (Omega Optical, Brattleboro, VT) had a center wavelength of 222 nm and a full width at  
129 half maximum (FWHM) of 25 nm and enables >20% transmission at 222 nm. A UV spectrometer  
130 (SPM-002-BT64, Photon Control, BC, Canada) with a sensitivity range between 190 nm and 400 nm  
131 was utilized to verify the 222 nm emission spectrum. A deuterium lamp standard with a NIST-traceable  
132 spectral irradiance (Newport Model 63945, Irvine, CA) was used to radiometrically calibrate the UV  
133 spectrometer.

134 **Far-UVC dosimetry.** Optical power measurements were performed using an 818-UV/DB low-power  
135 UV enhanced silicon photodetector with an 843-R optical power meter (Newport, Irvine, CA).  
136 Additional dosimetry to determine the uniformity of the UV exposure was performed using far-UVC  
137 sensitive film as described in our previous work<sup>28,29</sup>. This film has a high spatial resolution with the  
138 ability to resolve features to at least 25  $\mu\text{m}$ , and exhibits a nearly ideal cosine response<sup>30,31</sup>.

139 Measurements were taken between experiments therefore allowing placement of sensors inside the  
140 chamber.

141 A range of far-UVC exposures, from  $3.6 \mu\text{J}/\text{cm}^2$  up to  $281.6 \text{ mJ}/\text{cm}^2$ , were used to define a  
142 response calibration curve. Films were scanned as 48 bit RGB TIFF images at 150 dpi using an Epson  
143 Perfection V700 Photo flatbed scanner (Epson, Japan) and analyzed with radiochromic film analysis  
144 software<sup>32</sup> to calculate the total exposure based on measured changes in optical density.

145 Measurements using both a silicon detector and UV sensitive films were combined to compute  
146 the total dose received by a particle traversing the exposure window. The three vertically stacked lamps  
147 produced a nearly uniform dose distribution along the vertical axis thus every particle passing  
148 horizontally through the irradiation chamber received an identical dose. The lamp width (100 mm) was  
149 smaller than the width of the irradiation chamber window (260 mm) so the lamp power was higher near  
150 the center of the irradiation chamber window compared to the edge. The UV sensitive film indicated a  
151 power of approximately  $120 \mu\text{W}/\text{cm}^2$  in the center third of the window and  $70 \mu\text{W}/\text{cm}^2$  for the outer  
152 thirds. The silicon detector was used to quantify the reflectivity of the aluminum sheet at approximately  
153 15% of the incident power. Combining this data allowed the calculation of the average total dose of  $2.0$   
154  $\text{mJ}/\text{cm}^2$  to a particle traversing the window in 20 seconds. Additionally, the silicon detector was used to  
155 confirm the attenuation of 222-nm light through a single sheet of plastic film was 65%. The addition of  
156 one or two sheets of plastic film between the lamps and the irradiation chamber window yielded average  
157 doses of  $1.3 \text{ mJ}/\text{cm}^2$  and  $0.8 \text{ mJ}/\text{cm}^2$ , respectively.

158 **Benchtop aerosol irradiation chamber.** A one-pass, dynamic aerosol / virus irradiation chamber was  
159 constructed in a similar configuration to that used by Ko et al.<sup>33</sup>, Lai et al.<sup>34</sup>, and McDevitt et al.<sup>19,35</sup>. A  
160 schematic overview of the system is shown in Fig. 3. Aerosolized viruses were generated by adding a



161 virus solution into a high-output extended aerosol respiratory therapy (HEART) nebulizer (Westmed,  
162 Tucson, AZ) and operated using a dual-head pump (Thermo Fisher 420-2901-00FK, Waltham, MA)  
163 with an input flow rate of 11 L/min. The aerosolized virus flowed into the irradiation chamber where it  
164 was mixed with independently controlled inputs of humidified and dried air. Humidified air was  
165 produced by bubbling air through water, while dry air was provided by passing air through a desiccant  
166 air dryer (X06-02-00, Wilkerson Corp, Richland, MI). Adjusting the ratio of humid and dry air enabled  
167 control of the relative humidity (RH) within the irradiation chamber which, along with the nebulizer  
168 settings, determined the aerosol particle size distribution. An optimal RH value of 55% resulted in a  
169 distribution of aerosol particle sizes similar to the natural distribution from human coughing and  
170 breathing, which has been shown to be distributed around approximately 1  $\mu\text{m}$ , with a significant tail of  
171 particles less than 1  $\mu\text{m}$ <sup>36-38</sup>.

172         After combining the humidity control inputs with the aerosolized virus, input flow was directed  
173 through a series of baffles that promoted droplet drying and mixing to produce an even particle  
174 distribution<sup>34</sup>. The RH and temperature inside the irradiation chamber were monitored using an Omega  
175 RH32 meter (Omega Engineering Inc., Stamford, CT) immediately following the baffles. A Hal  
176 Technologies HAL-HPC300 particle sizer (Fontana, CA) was adjoined to the irradiation chamber to  
177 allow for sampling of particle sizes throughout operation.

178         During UV exposure, the three 222-nm lamps with filters were stacked vertically and placed 11  
179 cm from the irradiation chamber window. The lamps were directed at the 26 cm  $\times$  25.6 cm chamber  
180 window which was constructed of 254- $\mu\text{m}$  thick UV transparent plastic film (Topas 8007X10, Topas  
181 Advanced Polymers, Florence, KY), and which had a transmission of ~65% at 222 nm. The wall of the  
182 irradiation chamber opposite the transparent window was constructed with polished aluminum in order  
183 to reflect a portion of the UVC light back through the exposure region, therefore increasing the overall

184 exposure dose by having photons pass in both directions. The depth of the irradiation chamber between  
185 the window and the aluminum panel was 6.3 cm, creating a total exposure volume of 4.2 L.

186 Flow of the aerosols continues out of the irradiation chamber to a set of three way valves that  
187 could be configured to either pass through a bypass channel (used when no sampling was required), or a  
188 BioSampler (SKC Inc, Eighty Four, PA) used to collect the virus. The BioSampler uses sonic flow  
189 impingement upon a liquid surface to collect aerosols when operated at an air flow of 12.5 L/min.  
190 Finally, flow continued out of the system through a final HEPA filter and to a vacuum pump  
191 (WP6111560, EMD Millipore, Billerica, MA). The vacuum pump at the end of the system powered flow  
192 through the irradiation chamber. The flow rate through the system was governed by the BioSampler.  
193 Given the flow rate and the total exposure volume of the irradiation chamber, 4.2 L, a single aerosol  
194 droplet passed through the exposure volume in approximately 20 seconds.

195 The entire irradiation chamber was set up inside a certified class II type A2 biosafety cabinet  
196 (Labconco, Kansas City, MO). All air inputs and outputs were equipped with HEPA filters (GE  
197 Healthcare Bio-Sciences, Pittsburgh, PA) to prevent unwanted contamination from entering the chamber  
198 as well as to block any of the virus from releasing into the environment.

199 **Irradiation chamber performance.** The custom irradiation chamber simulated the transmission of  
200 aerosolized viruses produced via human coughing and breathing. The chamber operated at a relative  
201 humidity of 55% which resulted in a particle size distribution of 87% between 0.3  $\mu\text{m}$  and 0.5  $\mu\text{m}$ , 11%  
202 between 0.5  $\mu\text{m}$  and 0.7  $\mu\text{m}$ , and 2%  $> 0.7 \mu\text{m}$ . Aerosolized viruses were efficiently transmitted through  
203 the system as evidenced from the control (zero exposure) showing clear virus integration (Fig. 1, top  
204 left).

205 **Experimental protocol.** The virus solution in the nebulizer consisted of 1 ml of Dulbecco's Modified  
206 Eagle's Medium (DMEM, Life Technologies, Grand Island, NY) containing  $10^8$  focus forming units per  
207 ml (FFU/ml) of influenza A virus [A/PR/8/34 (H1N1)], 20 ml of deionized water, and 0.05 ml of Hank's  
208 Balanced Salt Solution with calcium and magnesium (HBSS<sup>++</sup>). The irradiation chamber was operated  
209 with aerosolized virus particles flowing through the chamber and the bypass channel for 15 minutes  
210 prior to sampling, in order to establish the desired RH value of ~55%. Sample collection initiated by  
211 changing air flow from the bypass channel to the BioSampler using the set of three way valves. The  
212 BioSampler was initially filled with 20 ml of HBSS<sup>++</sup> to capture the aerosol. During each sampling time,  
213 which lasted for 30 minutes, the inside of the irradiation chamber was exposed to 222 nm far-UVC light  
214 through the UVC semi-transparent plastic window. Variation of the far-UVC dose delivered to aerosol  
215 particles was achieved by inserting additional UVC semi-transparent plastic films, identical to the  
216 material used as the chamber window, between the lamps and the chamber window. The extra plastic  
217 films uniformly reduced the power entering the chamber. The three test doses of 0.8, 1.3 and 2.0  
218 mJ/cm<sup>2</sup>, were achieved by adding two, one, or no additional plastic films, respectively. Zero-dose  
219 control studies were conducted with the excimer lamps turned off. Experiments at each dose were  
220 repeated in triplicate. After the sampling period was completed the solution from the BioSampler was  
221 used for the virus infectivity assay.

222 **Virus infectivity assay.** We measured viral infectivity with a focus forming assay that employs  
223 standard fluorescent immunostaining techniques to detect infected host cells and infectious virus  
224 particles<sup>39</sup>. Briefly, after running through the irradiation chamber for 30 minutes, 0.5 ml of virus  
225 suspension collected from the BioSampler was overlaid on a monolayer of Madin-Darby Canine Kidney  
226 (MDCK) epithelial cells routinely grown in DMEM supplemented with 10% Fetal Bovine Serum (FBS),  
227 2 mM L-alanyl-L-glutamine, 100 U/ml penicillin and 100 µg/ml streptomycin (Sigma-Aldrich Corp. St.

228 Louis, MO, USA). Cells were incubated with the virus for 45 minutes, washed three times with HBSS<sup>++</sup>  
229 and incubated overnight in DMEM. Infected cells were then fixed in 100% ice cold methanol at 4°C for  
230 5 minutes and labeled with influenza A virus nucleoprotein antibody [C43] (Abcam ab128193,  
231 Cambridge, MA) 1:200 in HBSS<sup>++</sup> containing 1% bovine serum albumin (BSA; Sigma-Aldrich Corp.  
232 St. Louis, MO, USA) at room temperature for 30 minutes with gentle shaking. Cells were washed three  
233 times in HBSS<sup>++</sup> and labeled with goat anti-mouse Alexa Fluor-488 (Life Technologies, Grand Island,  
234 NY) 1:800 in HBSS<sup>++</sup> containing 1% BSA at room temperature for 30 minutes with gentle shaking.  
235 Following three washes in HBSS<sup>++</sup>, the cells were stained with Vectashield containing DAPI (4',6-  
236 diamidino-2-phenylindole) (Victor Laboratories, Burlingame, CA) and observed with the 10x and 40x  
237 objectives of an Olympus IX70 fluorescent microscope equipped with a Photometrics PVCAM high-  
238 resolution, high-efficiency digital camera. For each sample, at least three fields of view of merged DAPI  
239 and Alexa-488 images were acquired. Image-Pro Plus 6.0 software (Media Cybernetics, Bethesda, MD)  
240 was used to analyze the 10x images to measure the FFU<sub>UV</sub> as the ratio of cells infected with the virus  
241 divided by the total number of cells.

242 **Data analysis.** The surviving fraction (*S*) of the virus was calculated by dividing the fraction of cells  
243 that yielded positive virus growth at each UV dose (FFU<sub>UV</sub>) by the fraction at zero dose (FFU<sub>controls</sub>):  
244  $S = \text{FFU}_{\text{UV}} / \text{FFU}_{\text{controls}}$ . Survival values were calculated for each repeat experiment and natural log (ln)  
245 transformed to bring the error distribution closer to normal<sup>40</sup>. Linear regression was performed using  
246 these normalized ln[*S*] values as the dependent variable and UV dose (*D*, mJ/cm<sup>2</sup>) as the independent  
247 variable. Using this approach, the virus survival (*S*) was fitted to first-order kinetics according to the  
248 equation<sup>7</sup>:

$$249 \quad \ln[S] = -k \times D, \quad [1]$$

250 where  $k$  is the UV inactivation rate constant or susceptibility factor ( $\text{cm}^2/\text{mJ}$ ). The regression was  
251 performed with the intercept term set to zero, which represents the definition of 100% relative survival  
252 at zero UV dose. Bootstrap 95% confidence intervals for the parameter  $k$  were calculated using R 3.2.3  
253 software<sup>41</sup>. The virus inactivation cross section,  $D_{95}$ , which is the UV dose that inactivates 95% of the  
254 exposed virus, was calculated as  $D_{95} = -\ln[1 - 0.95]/k$ .

255

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348

349 **Author Contributions**

350 D.W., M.B., and V.G. designed and performed experiments, analyzed the data, and wrote the  
351 manuscript; I.S. analyzed the data; C.C. and A.W.B. designed the irradiation chamber; G.W.J.  
352 constructed the irradiation chamber; D.J.B and G.R-P. supervised, contributed conceptual advice, and  
353 wrote the manuscript. All authors discussed the results and commented on the manuscript.

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355 **Competing Interests**

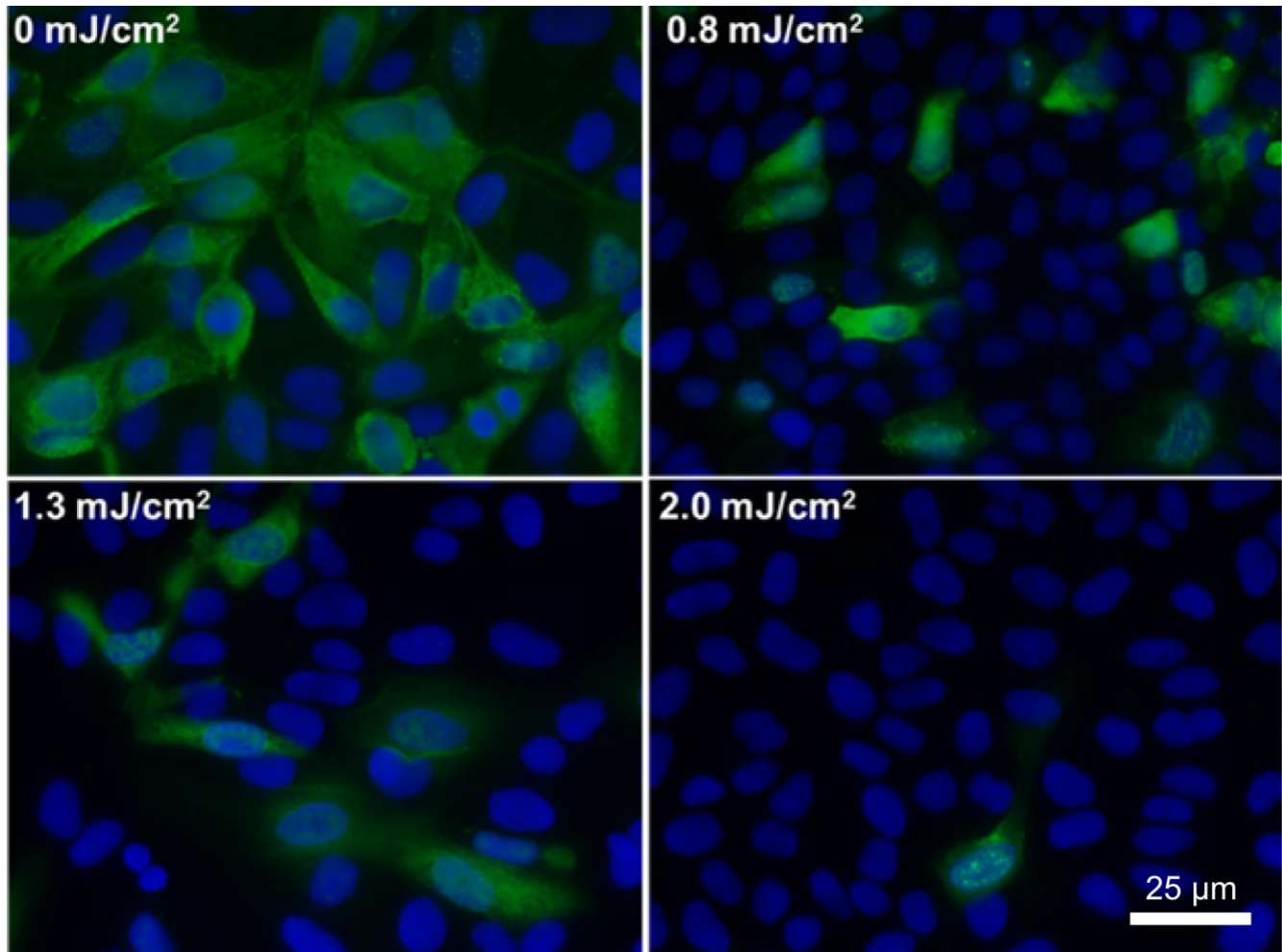
356 The authors declare that they have no competing interests.

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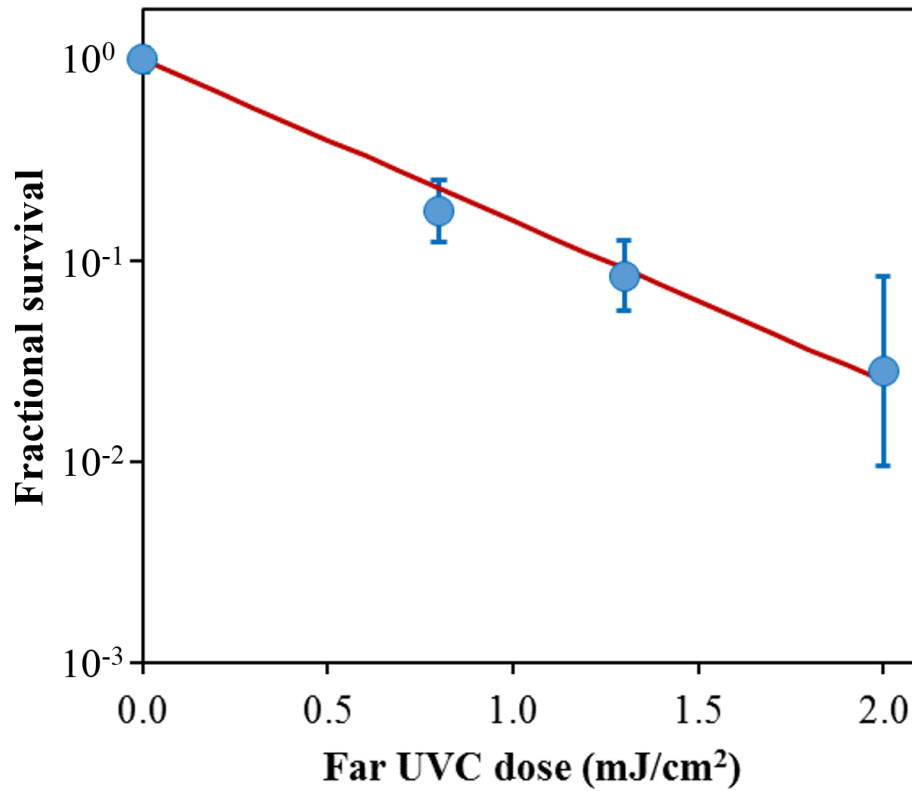
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363 **Figure 1 Antiviral efficacy of different low doses of 222-nm far-UVC light.** Typical fluorescent  
364 images of MDCK epithelial cells infected with influenza A virus (H1N1). The viruses were exposed in  
365 aerosolized form in the irradiation chamber to doses of 0, 0.8, 1.3 or 2.0 mJ/cm<sup>2</sup> of 222-nm far-UVC  
366 light. Infected cells fluoresce green (blue = nuclear stain DAPI; green= Alexa Fluor-488 conjugated to  
367 anti-influenza A antibody). Images were acquired with a 40x objective.

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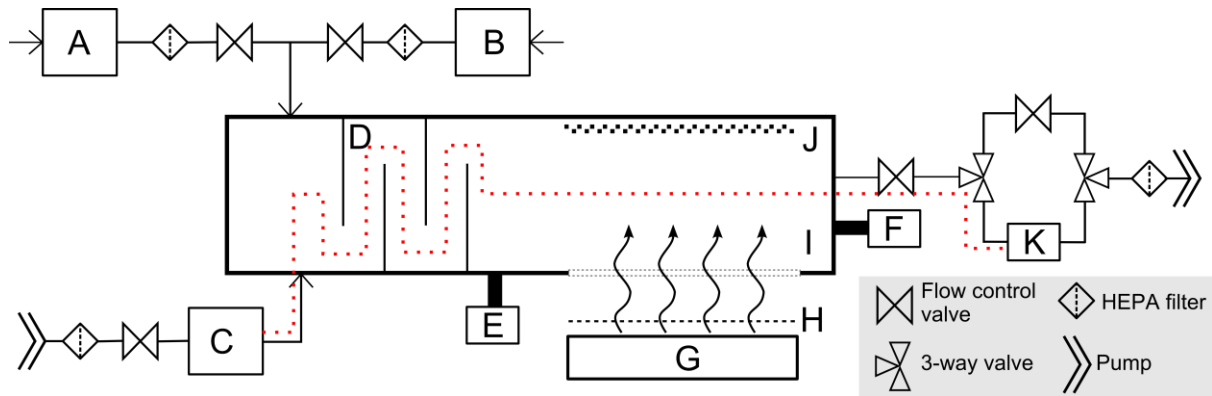
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373 **Figure 2 Quantification of the antiviral efficacy of 222-nm far-UVC light.** Fractional  
374 survival,  $FFU_{UV} / FFU_{controls}$ , is plotted as a function of the 222-nm far-UVC dose. Means and  
375 standard deviations refer to triplicate repeat studies and the line represents the best-fit  
376 regression to Eqn 1 (see text).

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381 **Figure 3 Schematic diagram of the custom UV irradiation chamber.** The chamber is depicted in a  
382 top down view. Components of the setup include: water bubbler for humidified air input (A), a desiccator  
383 for dry air input (B), a nebulizer (C), baffles (D), an RH and temperature meter (E), a particle sizer (F),  
384 far-UVC lamps (G), band pass filters (H), a far-UVC transmitting plastic window (I), a reflective  
385 aluminum surface (J), and a BioSampler (K). Pumps are used to pressurize the nebulizer for aerosol  
386 generation and to control flow through the system. Flow control valves allow adjustments through the  
387 system. HEPA filters are included on all air inputs and outputs. A set of three way valves controls flow  
388 to or around the BioSampler. The vertically stacked lamps are directed at the window in the side of the  
389 chamber to expose the aerosols passing horizontally. The additional films to uniformly decrease the  
390 dose were placed between the filters and the window. The path of the aerosolized virus within the  
391 system during sampling is indicated with the red dotted line.

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