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Development and Assessment of an Inexpensive Smartphone-Based Respiratory Droplet Simulation Model

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Abstract

Background. Droplet simulation often requires expensive and inaccessible equipment. Herein, we develop and assess a low-cost droplet simulation model using easily accessible materials, open-source software, and a smartphone-based cobalt blue light. *Methods.* The simulation model was developed using commercial-grade materials and fluorescein dye. A clear face shield was assessed ten times following a simulated cough using fluorescein dye. A conventional ultraviolet Woods lamp was compared to a smartphone-based cobalt blue light to detect fluorescein illumination. *Results.* The simulation platform and smartphone-based cobalt blue light cost $20.18. A Wilcoxon signed rank test revealed that the median droplet area of fluorescence under the UV Wood's lamp was not significantly different than that of the smartphone-based cobalt blue light (2.89 vs 2.94, P = .386). *Conclusions.* This simulation model is inexpensive and easily reproducible. The smartphone application may be a convenient alternative to standard ultraviolet lights. This model has great potential for use in financially restricted academic centers during the COVID-19 pandemic and beyond.

Keywords

smartphone, respiratory droplet, COVID-19, cobalt blue light, simulation, fluorescein

Introduction

The rise in SARS-CoV-2 infections worldwide has amassed increased interest in studying droplet dispersion within diverse surgical settings. Various simulations of respiratory droplet spread have been devised in order to assess personal protective equipment (PPE) and develop best practice guidelines for patient and provider safety.[1] Such studies model droplet size and/or dispersion through ultraviolet (UV)-visible cough simulators (e.g., fluorescein emitted from a mucosal atomization device (MAD), spray gun, or pressurized canister) placed within cadaver heads, medical mannequins, or human subjects.[2-4] However, these modes of simulation are often expensive, single-use, uncomfortable for human participants, and not readily accessible to researchers. Subsequently, we sought to identify an inexpensive, easily replicable means of assessing respiratory droplet spread using readily available materials, open-source software, and a smartphone-based cobalt blue light application.

Methods

This study did not require approval from the University of California, Irvine Institutional Review Board as it was considered a quality control initiative. A polystyrene mannequin head true to adult size was purchased and cut at the mouth to create an oral cavity. A bandage roll was folded to dimensions of 2 cm × 3 cm × 5 cm and placed within the cavity to mimic the tongue. Intravenous tubing was affixed to a mucosal atomization device (MAD Nasal, Teleflex, Morrisville, NC) that produces particles between

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Figure 1. Assembled respiratory droplet simulation model.

30 and 100 µm in size, inserted through the oral cavity into the base of the mannequin head, and connected to a 10-cc syringe with fluorescein dye. Assembly of these pieces was rapid and straightforward (Figure 1).

We used the aforementioned design to assess droplet spread on a commercially available clear plastic face shield following a simulated cough. A calibrated tape measure was printed and pasted on the face shield for scale. The face shield was fastened along the mannequin's forehead, and 2 cc of fluorescein dye was injected through the MAD to serve as a surrogate marker of contamination. Two means of illuminating the fluorescent dye were then objectively assessed. A conventional UV Woods lamp ($445.00, Lumio UV, Dermlite, San Juan Capistrano, CA) was compared to an iPhone 11 (Apple Inc., Cupertino, CA) displaying the cobalt blue light function on the $0.99 iOS-based smartphone application, All In One Ophthalmology. This mobile application, available on both iOS and Android-based devices, uses a specific RGB color model to display a blue hue on the smartphone device's liquid crystal display (LCD) screen which has been shown to illuminate fluorescein dye.[5,6] Photographs of the mannequin head were taken under each light source using a Samsung S20 smartphone (Samsung Group, Seoul, South Korea) (Figures 2A and 2B). This simulation was performed ten times.

The open-source Fiji software (ImageJ, Bethseda, Maryland) was used to calculate the area of fluorescent droplets in each image. First, the scale was set by measuring the number of pixels in one centimeter using the measuring tape included in the images. The *Split Channel* function separated each image into its respective red, green, and blue colors. The green image most prominently displayed the fluorescent droplets in greyscale and was selected for analysis. The *Threshold* function isolated the green color of the fluorescent droplets while concurrently minimizing surrounding artifact. The *Freehand Selection* tool was used to crop areas outside the region of interest. Finally, the *Analyze Particles* function calculated the remaining area of fluorescence (Figure 2C). Median fluorescein droplet area between the two light sources was compared using a Wilcoxon signed rank test, using $P < .05$ for significance.

Results

The fluorescein droplets from all three MAD attempts were readily visualized using both light sources. A Wilcoxon signed rank test revealed that the median droplet area of fluorescence under the UV Wood's lamp was not significantly different than that of the smartphone-based cobalt blue light (2.89 vs 2.94, $P = .386$). The total cost of our simulation platform using the smartphone application was $20.18. Importantly, the majority of supplies required to fabricate our droplet dispersion model could be recycled for multiple assessments.

Discussion

This design builds upon earlier works on respiratory droplet simulation models. Similar to previously described platforms, our setup simulates coughing episodes through the use of a MAD and fluorescein dye.[2-4,7-9] What makes our model unique is that it is constructed from items that are readily accessible, it is reusable, and it incorporates an inexpensive smartphone-based cobalt blue light for fluorescein illumination. The polystyrene mannequin head replaced cadaver heads or medical mannequins which are costly and may not be necessary for PPE assessment studies similar to ours. While our study focused on droplet spread from the oral cavity, future studies could easily modify the mannequin head to mimic droplet dispersion from the nasal cavity.

The efficacy of the smartphone application to illuminate fluorescein has been previously demonstrated for corneal injury detection.[5,6] In this study, it served as a convenient and inexpensive alternative to the UV Woods lamp, and illuminated the fluorescein dye in a similar fashion to the standard Woods lamp. Unlike prior studies that simply define the presence or absence of fluorescein dye through photographs, we used Fiji software to objectively measure

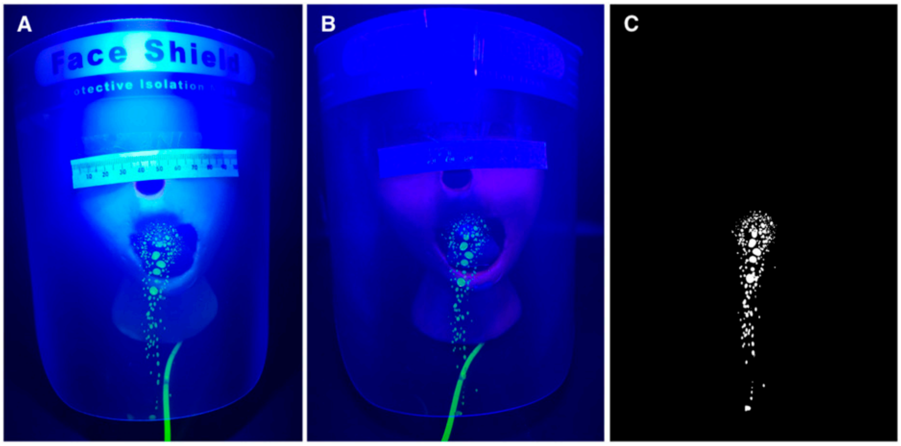

Figure 2. Fluorescein droplet dispersion under (A) Woods lamp and (B) smartphone-based cobalt blue light. (C) Open-source Fiji software was used to calculate the area of fluorescent droplets from the original images.

the total area of fluorescein emitted from the MAD. This is especially useful in simulation efforts that aim to calculate droplet size and/or area that is expelled following various clinical scenarios.

A fine balance exists between creating a simulation model that closely imitates reality while not being cost-prohibitive. Although our design presented several novel alternatives in droplet simulation modeling, it is not without limitations. The polystyrene mannequin was ideal for assessing PPE and may be appropriate to simulate respiratory droplet spread following certain minimally invasive procedures (e.g., nasal endoscopy and intubation), but it is likely insufficient to mimic droplet dispersion or aerosolization that occurs during more invasive surgical operations. Additionally, since the atomizer in our simulation produces sprays between 30 and 100 μm, smaller droplets were not formally assessed. Nevertheless, there has still been great interest in evaluating the spread of larger droplets as well as the coalescence of smaller droplets that may result from different clinical scenarios.[2-4,7-9] Further refinements in cough simulation technology are required to assess the dispersion of smaller droplets in relation to PPE evaluations. The MAD in our simulation may be readily replaced by such devices in future simulation endeavors.

Conclusions

Our goal was to describe the development of a simulation platform that models and calculates droplet dispersion using inexpensive, readily accessible materials; open-source software; and a smartphone-enabled cobalt blue light. We found that we could quickly and effectively assess a commercially available face shield for a total cost of $20.18. This setup has great potential to be used in financially restricted academic centers, to assess novel PPE designs, and to guide best practice guidelines during the COVID-19 pandemic and beyond.

Author Contributions

Amir Hakimi, BS: Conception and design of the study, acquisition and analysis of data, drafting the manuscript, and accountable for all aspects of the work. Dana M Hutchison, MS: Conception and design of the study, acquisition and analysis of data, drafting the manuscript, and accountable for all aspects of the work. Asher Park, BS: Conception and design of the study, acquisition and analysis of data, drafting the manuscript, and accountable for all aspects of the work. Natasha Atanaskova Mesinkovska, MD: Conception and design of the study, acquisition and analysis of data, drafting the manuscript, and accountable for all aspects of the work.
Sehwan Kim, PhD: Conception and design of the study, acquisition and analysis of data, drafting the manuscript, and accountable for all aspects of the work.
Phil-Sang Chung, MD, PhD: Conception and design of the study, acquisition and analysis of data, drafting the manuscript, and accountable for all aspects of the work.Brian J-F Wong, MD, PhD: Conception and design of the study, analysis and interpretation of data, drafting the manuscript, and accountable for all aspects of the work.

Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: Amir A. Hakimi performed the programming and development of the All In One Ophthalmology application. In addition, he receives royalties from application sales. The other authors have no relevant conflicts of interest to disclose.

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