Efficacy of Slit Lamp Breath Shields

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• PURPOSE: To evaluate the efficacy of slit lamp breath shields to prevent droplet spray from a simulated sneeze.
• DESIGN: Experimental study to test the effectiveness of personal protective equipment.
• METHODS: The nozzle of a spray gun was adjusted to angularly disperse a mist of colored dye that approximated a patient sneezing on a dimensionally accurate cardboard slit lamp model. The designs of 6 commercially available breath shields and 1 breath shield repurposed from a plastic container lid were tested. Each breath shield was sprayed in a standardized fashion 3 times, and the amount of overspray was compared to spray with no shield and quantified. The surface area that was sprayed was calculated using a commercially available software with color range function. The average percentage of overspray of each breath shield was computed in comparison to the control.
• RESULTS: The breath shields ranged in surface area from 116 to 924 cm^2, and the amount of overspray varied from 54% to virtually none. Larger breath shields offered better protection than smaller ones. Breath shields attached to the objective lens arm were better barriers than those of comparable size hung by the oculars. A repurposed plastic lid breath shield, 513 cm^2, was slightly curved toward the examiner's face and allowed only 2% overspray. The largest breath shield (924 cm^2) hung near the oculars and prevented essentially all overspray.
• CONCLUSIONS: The performance of different designs of breath shields was variable. Even high-functioning shields should be used in conjunction with personal protective equipment including masks, goggles, and gloves and handwashing. Ideally patients should also wear a face mask during all slit lamp examinations. (Am J Ophthalmol 2020;218:120–127. Crown Copyright © 2020 Published by Elsevier Inc. All rights reserved.)

THE NOVEL CORONAVIRUS 2019 (COVID-19) PANDEMIC is the most significant medical crisis of the 21st century thus far. COVID-19 is spread by droplets from talking, sneezing, or coughing and hand contact. Physicians from almost all specialties, including ophthalmologists, have died from COVID-19 contracted during their patient care duties.[1] Slit lamp breath shields are recommended to decrease the risk of possible infection to the examiner,[2] and numerous commercial and home-fabricated slit lamp breath shields are available.[3,4] Despite their pervasive use, this investigation did not find a formal study of the efficacy of slit lamp breath shields. This study tested and compared the performance of 6 commercially available breath shield designs and 1 breath shield repurposed from a plastic container lid in protecting examiners against respiratory droplets by using a spray gun-sneeze simulation.

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SUBJECTS AND METHODS

AN EXPERIMENTAL STUDY WAS CONDUCTED TO TEST THE effectiveness of personal protective equipment. On April 15, 2020, the search terms "slit lamp breath shield", "breath shield", and "ophthalmology" were used to survey the English language medical literature using Google Scholar, PubMed, and MEDLINE (Ovid). Articles from all years were searched. The Michael Garron Hospital Research Ethics Board deemed the study exempt. The study complied with all ethical research principles compatible with the Declaration of Helsinki, although no human experimentation was involved. Five different commercially available polyethylene terephthalate slit lamp breath shields were purchased online from ChinRestPaperSource (Hillsboro, Oregon); Reichert and Keeler (AMBC2P, Panfundus, Hillsboro, Oregon), Haag-Streit Regular (AMBC4P, Panfundus, Hillsboro, Oregon), Haag-Streit Improved (AMBC5P, Panfundus, Hillsboro, Oregon), Universal Small (AMBUS1P, Panfundus, Hillsboro, Oregon), and Universal Large (AMBUL1P Panfundus, Hillsboro, Oregon). The breath shields were chosen based on popularity, using Web site reviews. The largest commercially available breath shield, the "Zombie Shield" (AMBUZ, Panfundus), was also the most expensive and has been advertised for use during the COVID-19 pandemic.[5] Prior to the pandemic, conventional breath shields were much smaller than that shield. Due to budget constraints, dimensions of the sixth shield were simulated using cardboard. A seventh shield design consisted of a repurposed disposable plastic salad container lid and had edges that curved toward the examiner at roughly 35-degrees.

Using 4 different slit lamps (Haag-Streit BM900, Switzerland; Shin Nippon SL-102, Japan; Ibex 2-Step,

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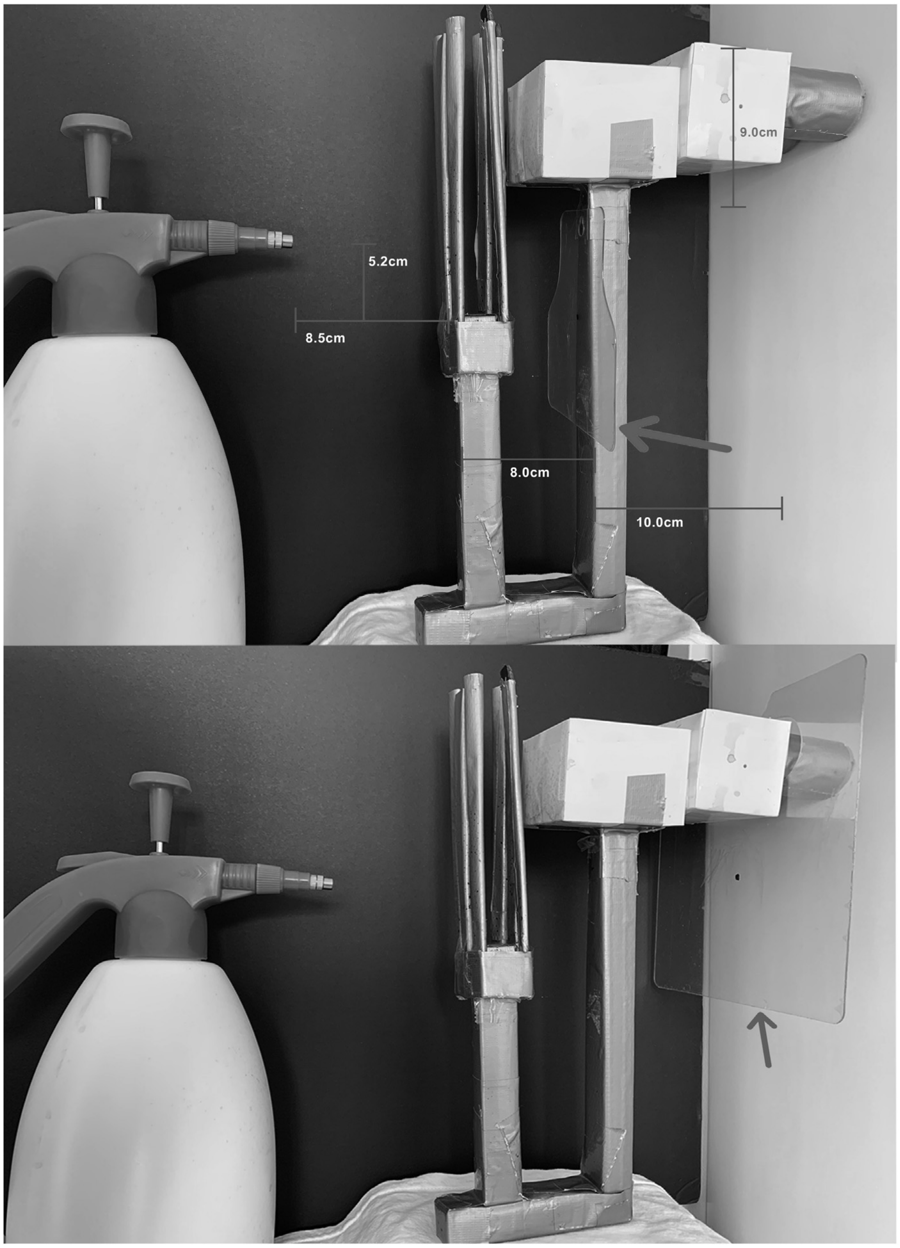


FIGURE 1. Spray gun and cardboard slit lamp simulation with setup measurements. Arrows indicate the positions of the breath shield. (Top) The breath shield is attached to the objective lens arm. (Bottom) The breath shield is hung by the oculars.

US; and Ray Vision SLR5, China), the horizontal distance from the chin rest to the center illuminating arm and to the arm of the objective lens was measured, using direct illumination while focused on a prosthetic eye in the corneal plane. The aforementioned slit lamp dimensions were averaged to make a dimensionally accurate cardboard slit lamp simulation. Our spray would be directed at the cardboard phantom at the height of the average menton-subnasale length (vertical height from the chin to the nares) that was determined from the medical literature.[6]

The angular dispersion of a spray droplet from a sneeze on the breath shield was estimated by using two methods: *(a)* published slow-motion videos[7] and *(b)* measurements of the angle of vapor condensation on a window 26 cm from the authors' lips on a cold day. A spray gun ("Nicely Neat," Mr. Mister, Seattle, Washington) was used to simulate a patient's sneeze. The nozzle of the spray bottle was adjusted to the study's derived dispersion angle, and the air pump was preloaded with 20 actuations to ensure a consistent force of spray at each breath shield. The speed of the spray was calculated by observing slow-motion video footage

FIGURE 2. Sample overspray patterns from control (top), a breath shield attached to the objective lens arm (1, Reichert and Keeler style, middle row), and a breath shield hung by the oculars (5, Universal Large, bottom row).

TABLE. Breath Shield Characteristics and Average Overspray

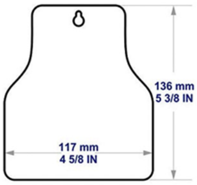
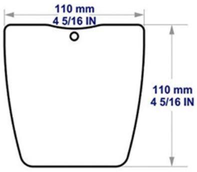
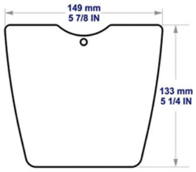
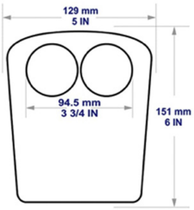
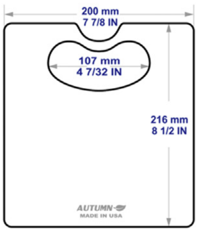
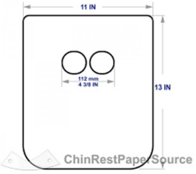
Manufacturer name, Product Code, and Position on Slit Lamp	Breath Shield Measurements L, W, SA	Configuration[5]	Average Area (cm^2) of Overspray $F_{(6,14)} = 10.63$; $P < .05$	Average % of Overspray Compared to Control
Control	NA	NA	$60.7\ cm^2 \pm 2.8\ cm^2$	Set at 100
Shield 1. Reichert and Keeler Style AMBC2P (Conventional) Attached to objective lens arm	Top section: L = 8 cm, W = 8 cm Bottom section: L = 6.5 cm W = 11.7 cm SA = 140 cm^2		$20.8\ cm^2 \pm 12.8\ cm^2$	34
Shield 2. Haag-Streit Style Regular AMBC4P (Conventional) Attached to objective lens arm	L = 11 cm W = 10.5 cm (measured in middle) SA = 115.5 cm^2		$4.9\ cm^2 \pm 2.5\ cm^2$	8
Shield 3. Haag-Streit Style Improved AMBC5P (conventional) Attached to objective lens arm	L = 13.3 cm W = 13.5 cm (measured in middle) SA = 179.6 cm^2		$2.0\ cm^2 \pm 1.6\ cm^2$	3
Shield 4. Universal Small AMBUS1P (conventional) Hung on oculars	L = 15.1 cm W = 12.3 cm (measured in middle) SA = 184.2 cm^2		$32.7\ cm^2 \pm 10.8\ cm^2$	54
Shield 5. Universal Large AMBUL1P (conventional) Hung on oculars	L = 21.6 cm W = 20.0 cm SA = 432 cm^2		$21.8\ cm^2 \pm 6.1\ cm^2$	36
Shield 6. Simulated "Zombie"-sized shield AMBUZ (nonconventional) Hung on oculars	L = 33 cm W = 28 cm SA = 924 cm^2		$0.2\ cm^2 \pm 0.01\ cm^2$	0.3

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TABLE. Breath Shield Characteristics and Average Overspray (*Continued*)

Manufacturer name, Product Code, and Position on Slit Lamp	Breath Shield Measurements L, W, SA	Configuration[5]	Average Area (cm^2) of Overspray $F_{(6,14)} = 10.63$; $P < .05$	Average % of Overspray Compared to Control
Shield 7. Repurposed Plastic Lid Shield (Non-Conventional) Attached to objective lens arm	Trapezoid Edges (4): Long base = 20.5 cm Short base = 13.25 cm Height = 5 cm Center square: L = 13.25 cm SA = 513.1 cm^2		1.1 cm^2 ± 1.7 cm^2	2

L = length; NA = not applicable; SA = surface area; W = width.

of the spray shot at 60 frames per second. The spray bottle was filled with water mixed with green food coloring dye.

The performance of each breath shield at blocking the spray was measured. The cardboard slit lamp model was placed at the appropriate distance and height from the spray gun, and white poster paper was positioned directly behind the oculars of the cardboard slit lamp model to catch any overspray. The cardboard phantom was sprayed without a breath shield to establish our baseline control area of spray. The measurement was repeated 3 times, each time using a new piece of poster paper. Then each breath shield was placed at its intended position, either on the objective lens arm or hanging off the oculars and tested 3 times. Figure 1 shows the cardboard slit lamp and spray bottle set up. The area of spray was photographed immediately after the spray (Figure 2). Photoshop software (Adobe, Mountain View, California) was used to determine the surface area of the green colorant. The color range function and Euclidean distances were used to calculate differences within the color space.[8] Any gravitational leakage of the colorant after the initial spray impression was accounted for. The average surface area from all 3 sets was calculated for each breath shield (Table).

RESULTS

NO STUDIES COULD BE FOUND IN THE MEDICAL LITERATURE evaluating the efficacy of slit lamp breath shields, with few studies mentioning slit lamp breath shields at all.

The average slit lamp horizontal distance measurement from the chin rest to the center illuminating arm was 8.5 cm; 8.0 cm from the center illuminating arm to the objective lens arm; and 10 cm from the objective lens arm to the oculars. A 16.5-cm distance was estimated from the patient's mouth to the breath shields that were attached to the objective lens arm, and 26.5 cm was the distance from the breath shields that were hung by the oculars (Figure 1) The vertical separation from the top of the breath shields attached to the objective lens arm and the top of the breath shields hung by oculars was 9 cm. The dimensionally accurate cardboard slit lamp phantom was constructed using the following averaged slit lamp measurements: *(a)* the illuminating arm was 7.5 × 3 × 3 cm at the base, with three 1.5-cm rods extending vertically from the base; *(b)* the objective lens apparatus incorporated a 2- × 2-cm rod supporting a 6- × 7- × 8-cm objective lens, connected to oculars measuring 9 × 6 × 6 cm (approximated as a box), with 5-cm-long cylinders at the end. The average menton-subnasale length at the chinrest was 5.2 cm[6] and confirmed by measuring the authors' faces. The average of the 2 methods for determining the angular dispersion of droplet spray from a sneeze was 47-degrees, and the speed of the spray gun was calculated at 2 m/s.

The Table shows each shield and its percentage of potential overspray. The range of the unblocked overspray varied from 0.3% to 54% versus the control surface area measurement. On analysis of variance, there were statistically significant differences among the performances of the 7 shields ($F_{6,14} = 10.63$; $P < .05$). The best performing breath shields were the largest shields (Table, shields 6 and 7) measuring 924 cm^2 and 513 cm^2, respectively. Those 2 shields performed significantly better than the best conventional commercial shield (Table, shield 3) on paired *t*-test analysis ($P = .028$; $P = .026$, respectively). Between the 2 Haag-Streit shields, the regular model (Table, shield 2) with surface area of 115.5 cm^2 and the "improved" model with a surface area of 179.6 cm^2 (Table, shield 3), the improved model blocked more spray, although this was not statistically significant ($P = .21$). The poorest performing breath shield measured at 184.2 cm^2 and was hung by the oculars (Table, 4).

Among conventional commercially available shields, the shields that were attached to the objective lens arm generally performed better but still allowed 3%, 8%, and

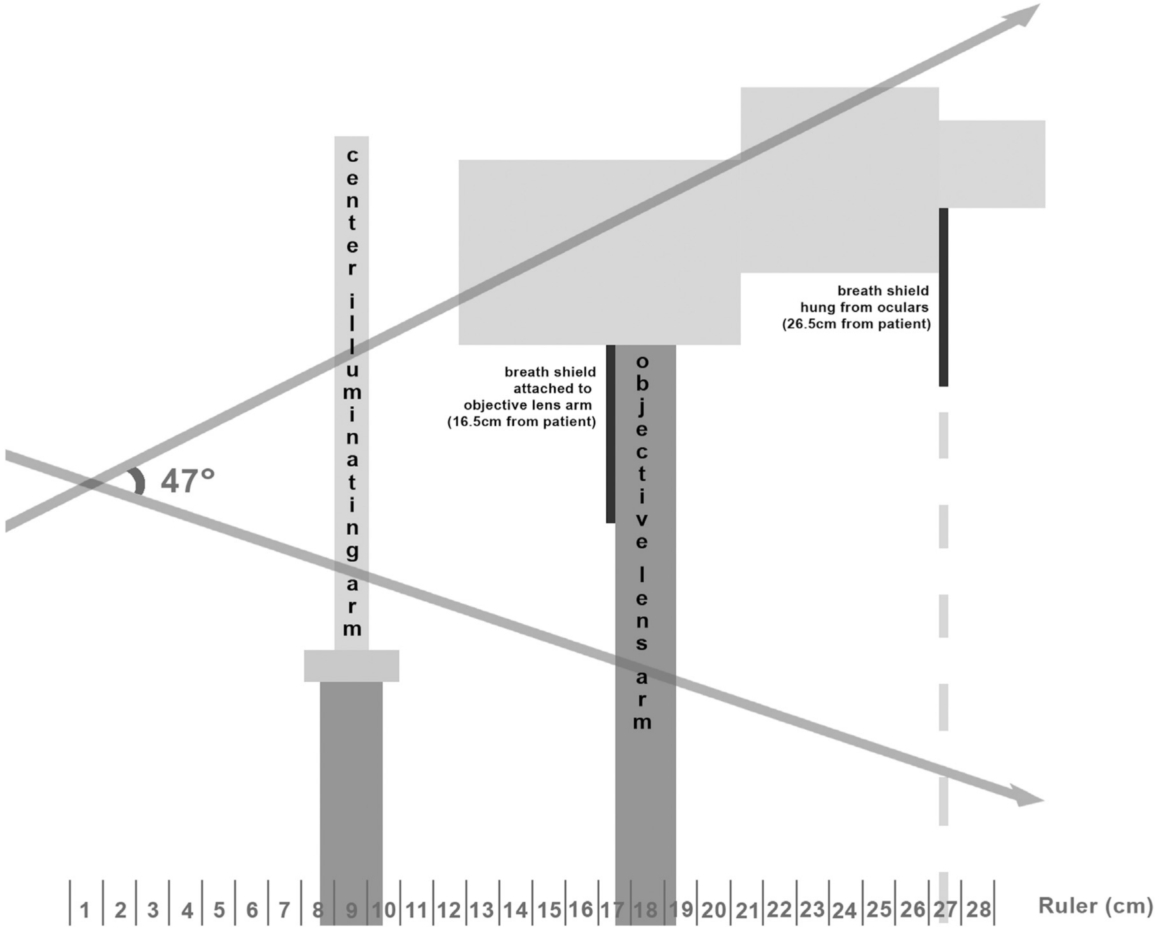

FIGURE 3. Dimensionally accurate ray diagram of the spray angle from a simulated sneeze. The slit lamp model is shown with breath shields placed in their appropriate relative positions.

34% of overspray. In contrast, the breath shields hung by the oculars did not protect against 36% and 54% of spray, respectively. Paired *t*-test analysis showed that the best performing conventional commercial breath shield mounted on the objective lens arm (Table, shield 3) performed significantly better than both conventional commercial breath shields hung by the oculars (Table, 4 and 5) ($P = .041$; $P = .017$, respectively). There were no statistically significant differences within any of the commercially available breath shields that were attached to the objective lens arm, nor were there any statistically significant differences within the 2 commercially available breath shields hung by the oculars.

DISCUSSION

OPHTHALMOLOGISTS MAY BE THE INITIAL CAREGIVERS FOR patients with COVID-19 who can be asymptomatic or present with conjunctivitis.[9–12] To date, at least 7 ophthalmologists have succumbed to COVID-19.[1] The late Dr. Li Wenliang, the "whistleblower" ophthalmologist from China, believed he was infected by an asymptomatic glaucoma patient.[13] Subsequently, 2 more of his ophthalmology colleagues at the same hospital died.

Appropriate protection is critical for ophthalmologists as we work near the airway and tears of patients, especially during slit lamp examinations. COVID-19 viral loads can be high in both symptomatic and asymptomatic patients,[14] suggesting universal precautions should be taken at the slit lamp regardless of whether patients are symptomatic, although the risk of ocular transmission of infection from tears of patients without conjunctivitis is purported to be low.[15] Patients are advised to no longer talk during slit lamp examinations. Examiners may be especially vulnerable when patients hyperventilate, cough, or sneeze at the slit lamp. Due to the photic sneeze reflex (or ACHOO syndrome), estimated to occur in 18%-35% of the population,[16] ophthalmologists may be at risk when exposing patients to bright lights. Sneezing may also occur with periocular injections due to the sternutatory reflex.[17]

To the best of the authors' knowledge, this is the first study that compares the designs of various slit lamp breath shields in the setting of a simulated ophthalmic examination. The study demonstrates that commercially available slit lamp breath shields may not block up to 54% of a 47-degree angle simulated oronasal spray. In this study, the more anteriorly fixed breath shields at the plane of the objective lens arm were more effective than the posteriorly positioned ocular shields of comparable size, consistent with "ray tracing" geometric principles (Figure 3). In our simulation, there was a 10-cm horizontal distance between breath shields attached to the objective lens arm versus breath shields hung by the oculars.

Size and shape are other factors that determine the performance of the breath shields. Of the 3 breath shields mounted on the objective arm, shield 3, with an area of 179.6 cm^2, was wider superiorly and allowed 5% less overspray than the similarly shaped shield 2 measuring 115.5 cm^2, and 31% less overspray than the superiorly tapered shield 1 of area 140 cm^2 (Table).

The repurposed plastic lid breath shield (courtesy of Dr. Brent Weiser and Dr. Sharon Weiser) was a plastic lid from a salad container, purchased at a local grocery store, yet it was superior to 5 of the 6 commercially available breath shield designs that were tested and can be easily replaced. Although larger shields may offer better protection, they may also impede access to slit lamp controls. A curved design such as in the repurposed plastic salad lid may protect the examiner from eccentric sneezes. There are other breath shield designs,[3] but the study did not have the resources to manufacture or test each one.

The study has limitations. Ideally both the patient and the physician should have face masks during the slit lamp examination, but when there is a shortage of PPE, the breath shields become even more important. As each slit lamp may be unique, the study results from the average dimensions of the cardboard phantom may not apply to other biomicroscopes. Only a straight-ahead spray was simulated; in reality, patients may sneeze at angles not blocked by the shield or slit lamp. Additionally, the spray velocity was 2 m/s, but sneezes can achieve a velocity of 35 m/s (126 km/h).[7] There were some variations in the spray measurements, which the authors attempted to minimize using 3 serial tests. The authors also could not quantify the volume of the overspray, which may correspond with that of the viral load only in the area. This is a limitation of the usage of imagery to capture the amount of overspray, as Photoshop cannot quantify the volume of water on the poster paper. Finally, the effects of microdroplets and aerosolization cannot be accounted for, which have been suggested as possible routes of transmission of COVID-19. Microdroplets are spread during a regular conversation and can rise high in the air and circulate well beyond the breath shield to reach the examiner.[18] The COVID-19 virus has been shown to stay viable in aerosols for at least 3 hours under experimental conditions in a Goldberg drum.[19]

Slit lamp breath shields should be combined with infection control measures and personal protection equipment.[20] Patients should be screened for symptoms of COVID-19 before arriving at the office, sit 2 m away from other patients, wear a face covering, and minimize any talking during the slit lamp examination. Ophthalmologists should use appropriate personal protection equipment including gloves, eye protection, a surgical mask, or an N95 respirator when necessary. Additionally, there should be proper ventilation in clinics and waiting areas, frequent handwashing, and proper disinfection of surfaces frequently touched by health care workers and patients, in addition to the breath shield.[21]

This study demonstrated that commercially available slit lamp breath shields may allow up to 54% of overspray contamination. Breath shields that are attached to the objective lens arm can be made larger to offer more protection but can impede access to slit lamp controls. Breath shields at the objective arm and plane of the oculars were not combined, but this can be done. A breath shield that curves toward the examiner such as our repurposed plastic lid design may better protect the examiner's face from eccentric sneezes. Breath shields should still be used in conjunction with other infection control measures to prevent the spread of COVID-19. Further research into protective devices against COVID-19 microdroplets is encouraged.

ALL AUTHORS HAVE COMPLETED AND SUBMITTED THE ICMJE FORM FOR DISCLOSURE OF POTENTIAL CONFLICTS OF INTEREST and none were reported.

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REFERENCES

1. Ing EB, Xu AQ, Salimi A, Torun N. Physician deaths from corona virus disease (COVID-19). *Occup Med (Lond)* 2020; https://doi.org/10.1093/occmed/kqaa088. https://academic.oup.com/occmed/article/doi/10.1093/occmed/kqaa088/5837392#203556249.
2. American Academy of Ophthalmology. Important coronavirus updates for ophthalmologists. Available at: 2020. https://www.aao.org/headline/alert-important-coronavirus-context. Accessed June 27, 2020.
3. Canadian Ophthalmological Society. Practice resource centre: 3 videos to make your own slit lamp protectors. Available at:

https://www.cosprc.ca/resource/3-videos-to-make-your-own-slit-lamp-protectors/. Accessed June 27, 2020.
4. Zeiss International. Slit lamp breath shields-Zeiss medical technology. Available at: https://www.zeiss.com/meditec/int/c/slit-lamp-breath-shields.html. Accessed April 7, 2020.
5. ChinRestPaperSource. Slit lamp breath shield, universal, extra large, zombie shield, thick acrylic. Available at: https://chinrestpapersource.com/zombie-shield. Accessed June 27, 2020.
6. Bradtmiller B, Friess M. A head-and-face anthropometric survey of U.S. respirator users. Final report. National Academies of Sciences Engineering Medicine. Available at: 2004. https://www.nap.edu/resource/11815/Anthrotech_report.pdf. Accessed June 27, 2020.
7. Scharfman BE, Techet AH, Bush JWM, Bourouiba L. Visualization of sneeze ejecta: steps of fluid fragmentation leading to respiratory droplets. *Exp Fluids* 2016;57(2):24.
8. Jarou Z. Measuring leaf area with adobe photoshop 3. Available at: https://www.youtube.com/watch?v=E3O-V6WLw0g. Accessed June 27, 2020.
9. Xia J, Tong J, Liu M, Shen Y, Guo D. Evaluation of coronavirus in tears and conjunctival secretions of patients with SARS-CoV-2 infection. *J Med Virol* 2020;6:589–594.
10. Guan W, Ni Z, Hu Y, et al. Clinical characteristics of coronavirus disease 2019 in China. *N Engl J Med February* 2020;382(18):1708–1720. https://doi.org/10.1056/NEJMoa2002032.
11. Wu P, Duan F, Luo C, et al. Characteristics of ocular findings of patients with coronavirus disease 2019 (COVID-19) in Hubei Province, China. *JAMA Ophthalmol March* 2020;138(5):575–578. https://doi.org/10.1001/jamaophthalmol.2020.1291.
12. Zhang Xian, Chen Xuhui, Chen Liwen, et al. The Evidence of SARS-CoV-2 Infection on Ocular Surface. *The Ocular Surface* 2020;18(3):360–362. https://doi.org/10.1016/j.jtos.2020.03.010.
13. Leung H. "An Eternal Hero." Whistleblower Doctor Who Sounded Alarm on Coronavirus Dies in China. Time Magazine. Available at: https://time.com/5779678/li-wenliang-coronavirus-china-doctor-death/. Accessed June 27, 2020.
14. Zou L, Ruan F, Huang M, et al. SARS-CoV-2 viral load in upper respiratory specimens of infected patients. *N Engl J Med* 2020;382:1177–1179.
15. Yu Jun IS, Anderson DE, Zheng Kang AE, et al. Assessing viral shedding and infectivity of tears in coronavirus disease 2019 (COVID-19) patients. *Ophthalmology* 2020; https://doi.org/10.1016/j.ophtha.2020.05.040. Online ahead of print.
16. Pagon RA. Why does bright light cause some people to sneeze? November 18, 2002. Scientific American. Available at: https://www.scientificamerican.com/article/why-does-bright-light-cau/. Accessed June 27, 2020.
17. Kulkarni OC, Cox CA, Hedges TR, Tarsy D. Sternutatory reflex induced by periocular needle insertion in patients receiving chronic botulinum toxin injections. *Parkinsonism Relat Disord* 2013;19(8):770–771.
18. NHK World-Japan. Reducing risk of microdroplet infection. Available at: 2020. https://www3.nhk.or.jp/nhkworld/en/news/ataglance/845/. Accessed June 27, 2020.
19. van Doremalen N, Bushmaker T, Morris DH, et al. Aerosol and surface stability of SARS-CoV-2 as compared with SARS-CoV-1. *N Engl J Med March* 2020;382:1564–1567. https://doi.org/10.1056/NEJMc2004973.
20. Olivia Li J-P, Shantha J, Wong TY, et al. Preparedness among ophthalmologists: during and beyond the COVID-19 Pandemic. *Ophthalmology* 2020;127(5):569–572. https://doi.org/10.1016/j.ophtha.2020.03.037.
21. Lai THT, Tang EWH, Chau SKY, Fung KSC, Li KKW. Stepping up infection control measures in ophthalmology during the novel coronavirus outbreak: an experience from Hong Kong. *Graefes Arch Clin Exp Ophthalmol* 2020;258(5):1049–1055. https://doi.org/10.1007/s00417-020-04641-8.