Efficacy of SG Shield in reducing droplet contamination during collection of oropharyngeal swab culture specimens

Phui-Sze Angie Au-Yong1, MBBS, MMed, Xuanxuan Chen1, MBBS, MMed, Wen Hao Low1, MBBS, MMed, Keen Chong Chau2, MBBS, Stephanie Fook-Chong3, MSc, CStat, Shariq Ali Khan1, MD, FRCA
1Department of Anaesthesiology, Singapore General Hospital, 2Department of Anaesthesiology Sengkang General Hospital, 3Health Services Research Unit, Singapore General Hospital, Singapore

Abstract

Introduction: Oropharyngeal swabs for diagnosis of COVID-19 often induce violent coughing, which can disperse infectious droplets onto providers. Incorrectly doffing personal protective equipment (PPE) increases the risk of transmission. A cheap, single-use variation of the face shield invented by a Singaporean team, SG Shield, aims to reduce this risk. This manikin study aimed to study the efficacy of the SG Shield in combination with standard PPE.

Methods: A person attired in full PPE whose face and chest was lined with grid paper stood in front of an airway manikin in an enclosed room. A small latex balloon containing ultraviolet fluorescent dye was placed in the oral cavity of the manikin and inflated until explosion to simulate a cough. Three study groups were tested: (a) control (no shield), (b) face shield and (c) SG Shield. The primary outcome was droplet dispersion, determined quantitatively by calculating the proportion of grid paper wall squares stained with fluorescent dye. The secondary outcome was the severity of provider contamination.

Results: The SG Shield significantly reduced droplet dispersion to 0% compared to the controls (99.0%, P = 0.001). The face shield also significantly reduced droplet contamination but to a lesser extent (80.0%) compared to the control group (P = 0.001). Although the qualitative severity of droplet contamination was significantly lower in both groups compared to the controls, the face shield group had more contamination of the provider’s head and neck.

Conclusion: The manikin study showed that the SG Shield significantly reduces droplet dispersion to the swab provider’s face and chest.

Keywords: COVID-19, droplet, face shield, oropharyngeal swab, SG Shield
Our institution, the Singapore General Hospital, Singapore, developed a single-use shield called SG Shield [Figures 1 and 2] to cope with the large volume of COVID-19 swabs. It is cheap and easy to upscale manufacturing. Both SG Shields and face shields are to be used together with full PPE. The SG Shield is lightweight and made of a thin sheet of polycarbonate measuring 21 cm × 34.5 cm × 0.3 cm. It comes with slots for a tongue depressor and swab stick, and can be readily assembled by the patient’s side. It is deployed close to the patient’s face during swabbing to catch any respiratory secretions generated by the patient.

This is a novel invention and has the potential to benefit the future development of shields for the protection of healthcare workers performing aerosol-generating procedures. The purpose of this simulation study was to assess the efficacy of the SG Shield in reducing droplet contamination for the swab provider when performing an oropharyngeal swab, using a simulated cough from the manikin. This was compared to having a face shield and no shield at all to assess the relative degree of protection these methods provide.

METHODS

Approval was sought from the SingHealth Institutional Review Board, but a review was not required, as the manikin simulation study did not involve human subjects and was deemed to pose no risk.

The study was conducted in a large, spacious enclosed room. A person (height 1.6 m) attired in full PPE, consisting of face mask, goggles, surgical cap and gown, stood 40 cm away (horizontal distance from person’s face to manikin’s mouth) from the front of an airway manikin (AirSim, TruCorp Pvt Ltd, Co. Armagh, North Ireland). The manikin’s mouth was taken as the point of reference for measurements. The manikin was angled at 30° vertically and at a height of 1.1 m from the ground to simulate the scenario of a typical swabbing station where the patient is sitting while the swab provider is standing [Figure 2]. The face and chest of the swab provider were lined with grid paper according to the boundaries that standard PPE would cover, which was divided into three areas: the goggle wall, mask wall and chest wall [Figure 3]. One grid measured 5 cm × 5 cm.

To approximate a forceful cough and generate a spread of aerosol and droplets, a small latex balloon containing an ultraviolet fluorescent dye with similar viscosity to respiratory secretions was placed in the oral cavity of the manikin, based on a technique by Canelli et al. The balloon was inflated with air from a mechanical pump, the Tonsim Air Compressor (TAP-03A; Huizhou Tonsim Intelligent Technology Co. Ltd, Guangdong, China) until the balloon exploded in a crude simulation of a cough. The dye inside the balloon would then land on the grid paper. The air pressure at which this explosion occurred was measured in pounds per square inch (PSI) with a pressure gauge attached to the mechanical pump to ensure standardised bursting pressures.

Three study groups were tested: (a) control group (no barrier), (b) face shield group (PPM Medical, Singapore) and (c) SG Shield group. After each simulated cough,
the manikin and the swab provider were illuminated with ultraviolet light to visualise the spread of the dye.

The primary outcome was spread of droplet dispersion, determined quantitatively by calculating the proportion of grid paper wall squares stained with fluorescent dye. The secondary outcome was a qualitative analysis of zones of contamination on the provider, determined according to a provider contamination severity (PCS) scale. This is a self-devised method for classifying the zones of contamination. Its purpose is to identify areas on the swab provider that are not covered by PPE and can be contaminated. On this scale, 0 represented no dye at all on the provider; 1 represented dye on the provider’s body but not the head, neck or face; 2 represented dye on the head and neck but not face; 3 represented dye on the face but not the eyes, nose and mouth; and 4 represented dye on the eyes, nose and mouth. We assigned a higher zone number to areas that are more vulnerable to being infected if infectious droplets landed, such as mucous membranes, assuming that skin area was intact at all times. The highest possible zone number was used for analysis.

A pilot study was conducted using the control group to calculate sample size. Results showed a droplet dispersion of 99%. Adequate protection with PPE should reduce this droplet dispersion by at least 80%. For the primary outcome, to detect a decrease in droplet dispersion from 99% in the control group to 20% in the PPE group, with a power of 80% and an alpha error of 0.05, five attempts would be required in each study group.

All data was analysed using Stata version 14.0 (StataCorp LP, College Station, TX77845, USA). Fisher’s exact test and Mann-Whitney U test were used for inter-group comparison for discrete and continuous data respectively. Statistical significance was defined as $P < 0.05$.

**RESULTS**

Five attempts were conducted for each study group [Table 1]. The SG Shield was able to significantly reduce the percentage of grid paper that was stained with dye, as 0% (95% confidence interval [CI] 0%–3.6%) of the grid paper walls were stained, as compared to 99.0% (95% CI 94.6%–100.0%) in the control group ($P = 0.001$). Quantitative droplet dispersion in the face shield group was also significantly reduced but not to as large an extent as the SG shield; 80.0% (95% CI 70.8%–87.3%) of the walls were stained compared to the control group ($P = 0.001$).

The severity of contamination of the provider was measured using the PCS scale [Box 1]. It was significantly lower in the face shield and SG Shield groups at 2 (interquartile range [IQR] 2–2) and 0 (IQR 0–0) compared to 4 (IQR 4–4) in the control group. The face shield group had more contamination of the provider’s head and neck (but not face) area, as indicated by a median PCS scale score of 2 and spatial droplet distribution of 0% (95% CI 0%–30.8%) and 0% (95% CI 0%–30.8%) on the goggle and mask walls [Table 2].

Simulated cough intensity, as measured using peak balloon pressure, was not significantly different between the face shield and SG Shield groups at 4.5 (IQR 4.5–4.5) PSI and 4.5 (IQR 4.5–4.5) PSI, respectively, compared to the control group with 4.0 (4.0–4.5) PSI.

**DISCUSSION**

Our results showed that the SG Shield significantly reduces droplet dispersion to areas of the swab provider’s face and chest during oropharyngeal swabbing, even with forceful coughing, and provides a better degree of protection compared to the face shield.

Infection of healthcare workers is a pressing worldwide concern, as millions of oropharyngeal swabs are being done worldwide with the resurgence of COVID-19 and over 90,000 healthcare workers have been infected. SARS-CoV-2 (severe acute respiratory syndrome coronavirus 2) has been shown to be transmitted in presymptomatic patients and can extensively contaminate the environment, as it thrives for long periods of time on surfaces. Coughing bouts can produce a dispersion distance of 460 ± 127 mm and has spurred many to create barriers to protect medical providers during procedures that generate aerosols but critics feel that these barriers have marginal benefits because they do not reduce or replace the use of PPE. However this fails to consider the transmissibility of infectious particles caused by incorrect doffing, which is related to the amount of respiratory secretions on the PPE. Phan et al. reported that 90% of observed doffing by healthcare workers caring for patients with viral respiratory infections was incorrect.

The standard face shield is not as effective as might be assumed in protecting against contamination over the face and neck areas. An interesting observation from our study was that there was droplet contamination on the neck with

| Measure                                      | Control       | Face shield  | SG Shield   | $P$  |
|----------------------------------------------|---------------|--------------|-------------|------|
| Total grid paper stained with dye* (%)       | 99.0 (94.6–100.0) | 80.0 (70.8–87.3) | 0.001       | 0 (0-3.6) | 0.001 |
| Droplet dispersion on PCS Scale*             | 4 (4–4)       | 2 (2–2)      | 0.003       | 0 (0–0)   | 0.003 |
| Balloon peak pressure* (PSI)                 | 4.0 (4.0–4.5) | 4.5 (4.5–4.5) | 0.050       | 4.5 (4.5–4.5) | 0.221 |

*Data presented as mean (95% confidence interval). †Data presented as median (interquartile range). PCS: provider contamination severity, PSI: pounds per square inch.
the use of the face shield but not SG Shield. The neck is an area that is often not covered by the local standard PPE, and the usual practice of changing PPE in between patients will not remove these respiratory droplets. The SG Shield thus improves protection by ensuring minimal contamination of the vulnerable neck area.

We hypothesise that the SG Shield may work better because the barrier is held close to the source of aerosol and droplet production, and hence most of the respiratory secretions are caught before they can escape into the environment or splatter onto the provider. Some may argue that as long as there is no broken skin or exposed mucosa, the virus is unlikely to enter the body. This may be challenged in immunocompromised hosts and the elderly. It is also probably more efficacious to reduce the viral burden at the source rather than prevent environmental contamination, given that it is logistically taxing to wipe down or change PPE between patients.

The strengths of the study are that the experiment was conducted in a controlled and highly reproducible environment and tries to capture aerosol dispersal in the provider’s direction in a clinically meaningful way. Although done offsite, it simulates the real-world scenario with the use of actual equipment.

One of the limitations of this study is the small sample size, which may be inadequate to detect a smaller effect size. However, there was very little variation within the same group, and further attempts are unlikely to change the results. Secondly, there may be inter-individual variation in cough generation and aerosol contamination depending on external factors such as environment and wind direction, head positioning and swab technique used. Thirdly, the cough was simulated by hyperinflating latex balloons until they burst at pressures of about 4 PSI. Although we tried to simulate the pressures of the average cough reflex around 3 PSI, these simulated coughs that were at slightly supranormal pressures were the closest we could achieve. Further research could utilise this method with a scientific particle counter to ascertain the actual number of particles that were produced and caused provider contamination.

In conclusion, our study showed that the standard face shield is inadequate for protecting against droplet dispersion during oropharyngeal COVID-19 swabs. Consideration should be given to adopt the design of the SG Shield to reduce contamination of the environment and provider at the source.

Acknowledgements

We would like to thank our leadership, A/Prof Soh Chai Rick and Dr Tan Kian Hian (Singapore General Hospital), and Dr Teo Li Ming (Sengkang General Hospital) for their overall research support, the SingHealth Duke-NUS Institute of Medical Simulation for their loan of the manikin and the SingHealth team led by Dr SR Sudirman for creating SG Shield.

Financial support and sponsorship

This work was sponsored by the Division of Anaesthesiology and Perioperative Medicine, Singapore General Hospital.

Conflicts of interest

There are no conflicts of interest.

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