

Filtration efficiency of face masks and veils as protective measures during COVID-19 pandemic

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Abstract

Wearing face masks have been implemented as a public and personal health control measure against the spread of coronavirus disease (COVID-19). However, the protection level of non-medical face masks, such as women face veils, is still uncertain. This study aimed to assess the filtration efficiency (FE; percentage of particles retained by a mask) of different types of medical masks (either as sealed or unsealed, single or doubled), non-medical masks (cloth masks) and face veils. FE of face masks was evaluated using an in-house 3D-printed air duct connected to the Aerotrak particle counter with a capability of counting particle sizes of 0.3, 0.5, 0.7, 1, 2 and 5 μm . A set of 10 earloop surgical masks, 10 tie-on surgical masks, 3 triple-layers reusable cloth masks and 3 types (short, medium and long) of traditional face veils were included in the study. The unsealed surgical masks showed intermediate FE (36.54-80.58%), with no observed differences between tie-on and earloop or single and doubled masks. For each mask type, the mean FE values of sealed surgical masks ($\text{FE} \geq 99.16\%$) was significantly higher ($P < 0.001$) than the unsealed ones ($\text{FE} \leq 80.58\%$). No significant difference was observed in the mean FE values between unsealed surgical masks and either cloth masks ($\text{FE} = 23.19\text{-}75.35\%$, $P = 0.26$) or face veils ($\text{FE} = 19.10\text{-}70.68\%$, $P = 0.14$). However, a mockup experiment showed that wearing a surgical mask under the face veil significantly improve the FE (33.73-79.18%; $P < 0.001$). We conclude that besides sealed surgical masks that ensure optimal filtration under the experimental conditions, the unsealed surgical and cloth masks and face veils showed comparable performance and acceptable protection at 5 μm particle size, which is the most relevant particle size associated with COVID-19 infectious droplets. Wearing a surgical mask under the face veil significantly improves the FE compared to wearing a face veil alone.

Keywords: COVID-19; filtration efficiency; face masks; face veils; surgical masks.

1. Introduction

The coronavirus disease (COVID-19) caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) was declared as a Public Health Emergency of International Concern (PHEIC) by the end of January 2020 and a pandemic on 11 March (World Health Organization (WHO), 2020d;

2021a). The disease that started in China in December 2019 affected, by the end of July 2021, more than 198 million individuals around the world including 4.2 million deaths (World Health Organization (WHO), 2021b).

The transmission of SARS-CoV-2 viruses is thought to occur primarily through respiratory droplets (>5 μm) released from infected patients during coughing, sneezing or speaking, and then transmitted to another healthy person by fomite transmission (Kim *et al.*, 2020; Nak-Jung *et al.*, 2020; O'Dowd *et al.*, 2020). Another important transmission mechanism is smaller aerosols (i.e., <5 μm) which remain airborne for long time and can lead to transmission in poorly ventilated environments (Sosnowski, 2021; Tang *et al.*, 2021). Therefore, wearing disposable surgical masks, in addition to other preventive measures such as hand hygiene and social distancing, have been strongly recommended by World Health Organization (WHO) to be worn in public places to prevent the spread of SARS-CoV-2 transmission (World Health Organization (WHO), 2020c). Consequently, wearing surgical masks was implemented in more than 100 countries as one of the mandatory general precautionary measures in public places, public transportation and indoor spaces (Bussemaker, 2020). As a result, a global shortage of surgical masks occurred, evoking using reusable cloth (textile) face masks in non-medical settings (Ji *et al.*, 2020). The surgical and cloth masks' efficacy has been extensively studied in terms of filtration efficiency, reusability and material stability (Roberge, 2008; European Centre for Disease Prevention and Control, 2020; Szarpak *et al.*, 2020; Zangmeister *et al.*, 2020). However, there is limited guidance and experimental data comparing the protection degree between tie-on and earloop surgical masks, single and double surgical masks and sealed and unsealed surgical masks (Huang & Huang, 2007; Grinshpun *et al.*, 2009; Sanchez, 2010)

Furthermore, there is a lack of data regarding the protection level of other face mask alternatives used in certain societies such as face veils. In general, face veils are ornamental or functional dresses, used more often by women than men, in certain societies for variable purposes and different beliefs. The face veils are made from either silk, cotton, chiffon or a mixture of these materials. A number of scientific-social debates were raised in the media about whether face veils provide adequate protection as ordinary face masks, with no experimental data available to settle this debate (Caldera, 2020; Perolini, 2020). Only two studies reported that face veils were used in certain countries as an alternative to the face mask during the COVID-19 pandemic (Noushad & Al-Saqqaf, 2021; Raja *et al.*, 2021). However, no experimental data was reported to support this assumption. v

The current study aimed to assess the filtration efficiency (FE) of different types of medical masks (tie-on and earloop surgical masks) either as sealed and unsealed masks or as single or double masks. Furthermore, the study evaluated the FE of non-medical masks such as cloth masks and face veils.

2. Materials and Methods

2.1 Medical and non-medical masks

The description of the face masks and veils used in the study is presented in Table 1. Briefly, 2 types of fiber medical masks (earloop and tie-on masks) and non-medical mask (cloth masks), and face veils were used.

Table 1: Description of the face masks and veils used in this study.

Face mask	Type	Company	Country	Lot number
<u>Medical:</u>				
Earloop mask	Surgical mask	Enayah	Saudi Arabia	6281141017551
Tie-on mask	Surgical mask	Damad	Saudi Arabia	322004W16
<u>Non-medical:</u>				
Cloth mask (triple-layers)	Non-Medical	KFSH&RC Souvenir Store	Saudi Arabia	NA
Face veils (3 types)	Traditional dress	Local handcraft	Saudi Arabia	NA

A set of 10 earloop surgical masks (Enayah), 10 tie-on surgical masks (Damad), 3 triple layers reusable cloth masks (purchased from KFSH&RC Souvenir Store) and 9 traditional women face veils (3 short; from nose to chin, 3 medium; from nose to neck and 3 long; from nose to upper chest) were included in the study. The two types of surgical masks are manufactured locally, and they were selected as they are widely used in Saudi Arabia during the COVID-19 pandemic. The surgical masks' FE was measured either as single or doubled masks and either sealed or unsealed masks.

2.2 Filtration efficiency (FE) measurement

The FE measurement used in this study is an in-house method that was previously described (Al-Hadyan *et al.*, 2021). Briefly, a custom-designed air duct was locally designed to measure the FE of medical and non-medical masks using the ambient particulate matter (PM) air as a source of the measured particles. The air duct consists of two parts, head and tail. The head part is connected to an AeroTrak particle counter (TSI, Model 9306) that counts particles with sizes of 0.3, 0.5, 0.7, 1, 2 and 5 μm for a sampling time of 1 minute at a flow rate of 2.8 liters/minute (L/min) with a storage capability of 10,000 measurements. The tail part is tied to an electrical fan that flows the PM air from the tail, all over the duct, to the head part. The fan is controlled by a variable transformer (model: 3PF1010, Staco Energy Production Company) fixed at 47 volts to give an air face velocity of 0.4 m/s; measured by Velocicalc Air Velocity Meter 9545 (TSI, product ID# 9545-A). One measurement was carried out for each mask or veil, with a total of 104 tests for all masks and face veils used in this study.

In the case of FE assessment of sealed surgical masks, the two parts of the air duct are tied together by three mold bolts to squeeze the mask to prevent any air from sneak between both parts. For the unsealed surgical masks, cloth masks and face veils, FE was assessed to mimic their actual use where the external air can sneak into the user's face from both cheek sides. Therefore, head and tail parts were loosely connected (untied mold bolts) during the FE assessment. In addition, the FEs of face veil alone and surgical mask worn beneath face veil were assessed in a mockup experiment as they may be worn together.

For each particle size, FE of each mask was calculated using the following formula:

$$FE(\%) = 100 - \left(\frac{\text{number of penetrated particles}}{\text{average number of particles in air}} \times 100 \right)$$

2.3 Statistical analysis

The parametric one way repeated measures analysis of variance test has been used to detect significant differences in means of different sets of data (Pervez *et al.*, 2017; Farooq & Freed, 2018). Therefore, it was used to detect significant differences in the FE means for each set of data obtained in this study. In case the data did not pass the normality test, the nonparametric Friedman Repeated Measures Analysis of Variance on Ranks test, which compares medians, was applied.

3. Results

The sealed surgical masks (for both types, earloop and tie-on), either single or doubled, showed high FE (99.16-100%) for all particle sizes (Figure 1). However, the unsealed surgical masks, for both types, showed intermediate FE (36.54-80.58%) either as a single (FE=36.54-76.67%) or double masks (FE=59.01-80.58%). The One Way Repeated Measures Analysis of Variance test showed statistically significant differences in the mean FE values between the sealed and the unsealed surgical masks for each type (earloop or tie-on), whether single or doubled masks (P<0.001) (Supplementary Materials 1 and 2).

As shown in Figure 2-A, a mockup experiment showed that long face veils showed higher FE (32.02-79.83%) than short face veils (09.03-61.62%), medium face veils (18.24-70.59%) and cloth masks (23.2-75.3%). Overall, the average FE of the veils (19.1-70.7%) was somewhat comparable to the FE of the unsealed single surgical masks (37.41-66.39%), the unsealed tie-on surgical masks plus veil (33.73-79.18%) and the cloth masks (23.19-75.35%). Statistically, the results showed no significant differences in the means FE values between wearing a surgical mask and either a surgical mask plus (under) veils (P=0.136) or cloth mask (P=0.261) (Supplementary Material 3). However, the mean FE values of wearing a surgical mask under the veil were significantly higher (P<0.001) than wearing the veil alone. Overall, all masks and face veils showed better FE with increasing particle diameter (Figure 2-B).

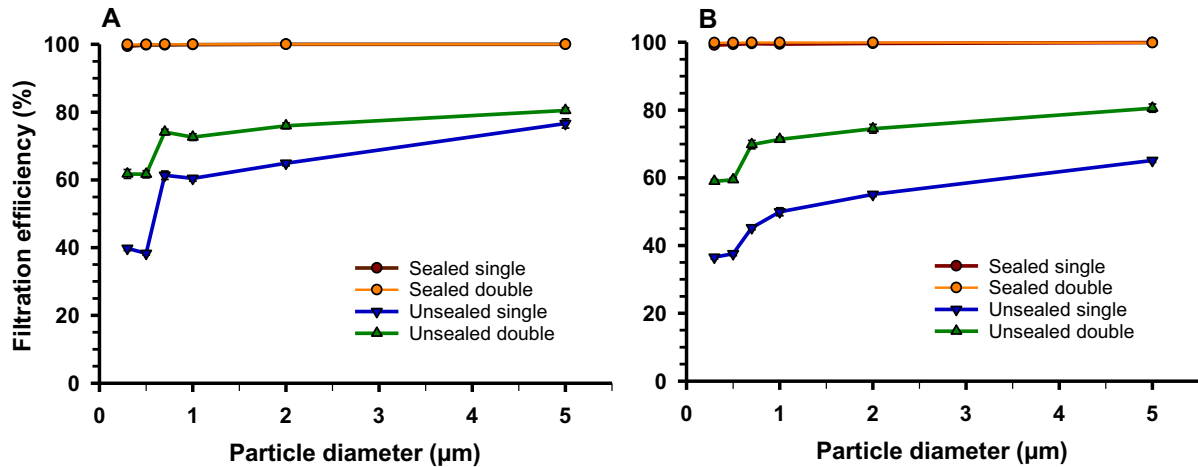


Fig. 1. Filtration efficiency (FE) of surgical earloop and tie-on surgical masks. Ten of each earloop (A) and tie-on (B) surgical masks were applied to FE evaluation for different particle sizes (0.3-5 µm) using Aerotrak particle counter. The FE of the surgical masks were measured either as single or doubled masks and either as sealed or unsealed masks. Results showed significant differences in the mean FE values between the sealed and the unsealed surgical masks for both mask types (earloop or tie-on) whether single or doubled masks ($P < 0.001$). The average PM concentrations (control) at 0.3, 0.5, 0.7, 1, 2 and 5 µm.were 61697.3 (standard deviations ‘STD’= 7637.7), 4660.8 (STD= 469.5), 245.5 (STD= 22.3), 818.5 (STD= 80.9), 864.3 (STD= 123.7) and 217.3 (STD= 42.9) respectively. Symbols represent the means, while error bars, which were smaller than the symbol size, indicate the standard error.

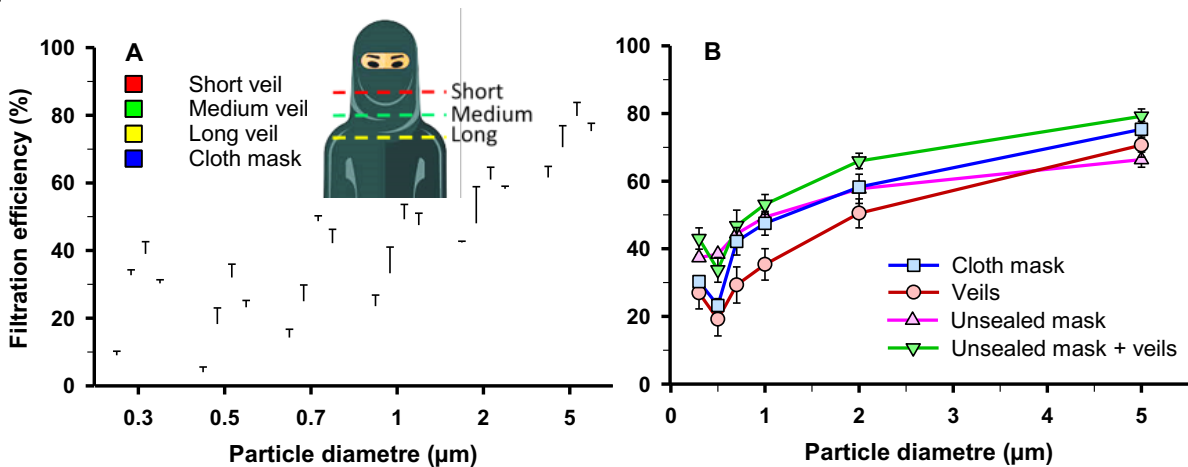


Fig. 2. Filtration efficiency (FE) of unsealed surgical masks, veil and cloth masks. A. FE of short (n=3), medium (n=3) and long (n=3) veils and cotton mask (n=3). B. FE of unsealed single tie-on masks (n=3), FE average of face veils (N=9, 3 short, 3 medium and 3 long) and cotton masks (n=3). All masks and face veils were applied to FE evaluation for different particle sizes (0.3-5 µm). Results showed no significant differences in the means FE values between wearing a surgical mask and either a surgical mask plus (under) veils ($P = 0.136$) or cloth mask ($P = 0.261$). The average PM concentrations (control) at 0.3, 0.5, 0.7, 1, 2 and 5 µm.were 46530.5 (STD= 873.3), 3257.5 (STD= 264.1), 118.2 (STD= 14.4), 385.5 (STD= 28.9), 374.4 (STD= 88.0) and 119.0 (STD= 38.1) respectively. Symbols represent the mean and error bars indicate the standard error.

4. Discussion

This study evaluated the FE of medical masks (tie-on and earloop surgical masks) and non-medical masks (cloth masks and face veils). The results indicated that the unsealed surgical masks exhibited intermediate FE (36.54-80.58%), with no observed differences between tie-on and earloop or single and doubled masks (Figure 1). For each mask type, the mean FE values of sealed surgical masks ($FE \geq 99.16\%$) was significantly higher ($P < 0.001$) than the unsealed ones ($FE \leq 80.58\%$). In addition, no significant difference was observed in the mean FE values between unsealed surgical masks and either cloth masks ($FE = 23.19-75.35\%$, $P = 0.26$) or face veils ($FE = 19.10-70.68\%$, $P = 0.14$) (Figure 2). However, wearing a surgical mask under the face veil significantly improve the FE (33.73-79.18%; $P < 0.001$). Furthermore, the in-house FE procedure used in this study is developed as an emergency alternative to the USA National Institute for Occupational Safety and Health (NIOSH) FE procedure to validate face masks during the COVID-19 pandemic (Al-Hadyan et al., 2021).

Unlike N95 Filtering Facepiece Respirators (FFRs), it is challenging to wear sealed surgical masks due to the difficulty of exporting exhaled gas, resulting in an accumulation of exhaust gas in the surgical mask and subsequently causing difficulty breathing (Huang & Huang, 2007; Skaria & Smaldone, 2014). Nevertheless, we have studied the FE of sealed surgical masks as healthcare frontliners have used them in case of a significant shortage of FFRs during the COVID-19 pandemic (Ekprechakul *et al.*, 2020; O'Kelly *et al.*, 2020; Ekprechakul *et al.*, 2021).

The results indicated that sealed surgical masks, yet impractical, could give a similar FE of N95 masks by blocking at least 99.2 for all particle sizes (Figure 1). In contrast, unsealed surgical masks showed intermediate FE (36.54-80.58%) with no observed differences between either tie-on and earloop masks or single and doubled masks. Three studies support our findings by reporting comparable FE results between sealed surgical masks and N95 respirators against airborne filtration (Noti *et al.*, 2012; Skaria & Smaldone, 2014; Karuppasamy & Obuchowski, 2021). In disagreement with our findings, the sealed surgical masks and cloth masks showed an average FE of 44.1% and 13.9% respectively (Joshi *et al.*, 2020). Another study showed lower FE of the sealed surgical masks than our findings, with FE of 51%, 84% and 85% at 0.5, 1 and 2 μm respectively (Sanchez, 2010). In agreement with our results, the latter study showed intermediate FE of the unsealed surgical masks, with FE of 43%, 75% and 79% at particle sizes of 0.5, 1 and 2 μm respectively.

A unique feature of this study is the measurement of the FE of face veils worn by individual women to cover parts of their faces. The assessment of their FE is important due to the lack of data on the face veils filtration capability as compared to other cloths and medical masks. Interestingly, our findings showed that the face veils ($FE = 19.10-70.68\%$) displayed comparable FE to either unsealed surgical masks (37.41-66.39%) or cloth masks (23.19-75.35%), suggesting that face veils, surgical and cloth offer a similar degree of protection (Figure 2). Irrespective of the breathing difficulties that they may cause, our data showed that surgical mask, when worn under the veil provides a higher degree of protection than wearing a face veil alone. It was also observed that long face veil has better FE than either medium or short face veils, making veil's size is an

important factor that affects veils' FE. Also, our data observed that cloth mask (FE=23.2-75.4%) and unsealed surgical mask (FE=37.4-66.4%) offered comparable FE at particle sizes between 0.3 and 5 μm . In agreement with our findings, a recent report showed almost equal FE of cloth masks (FE=19.5-81.8%) and unsealed surgical masks (FE=20.8-77.3%) at particle sizes between 0.3 and 5 μm (Kumar *et al.*, 2020).

Overall, all masks and face veils showed better FE with increasing particle diameter (Figure 2-B). These differences in the FEs across different particle sizes may have an implication on the current understanding of SARS-CoV-2 transmission. The size of the SARS-CoV-2 virus is $<1.0 \mu\text{m}$; however, it is transmitted through respiratory droplets ($>5 \mu\text{m}$) released from COVID-19 patients to another healthy person by fomite transmission (Kim *et al.*, 2020; Nak-Jung *et al.*, 2020; O'Dowd *et al.*, 2020). Although droplet nuclei particles ($<5 \mu\text{m}$) were not implicated to be a main transmission route of SARS-CoV-2 (World Health Organization (WHO), 2020a; 2020b; 2021a), recent reports indicated that droplet nuclei particles might play a more prominent role in SARS-CoV-2 transmission (Liu *et al.*, 2020; Ong *et al.*, 2020). A recent manuscript reviewed data from a number of experimental studies and theoretical models showed that the minimum size of droplets that contains and then transmit SARS-CoV-2 was $\sim 4.7 \mu\text{m}$ (Lee, 2020). Therefore, the particle size of 5 μm seems to be the most important size for the evaluation of the SARS-CoV-2 transmission.

Finally, it is important to note that the FE assessment in this study is based on mockup experiments to mimic the actual wearing of masks by individuals. However, other studies observed some differences in the efficiency between the mockup and actual wearing of masks (Cherrie *et al.*, 2018; Mueller *et al.*, 2018; Steinle *et al.*, 2018). Further studies using appropriate custom-designed phantoms are needed to mimic actual mask performance.

5. Conclusion

Besides sealed surgical masks that ensure optimal filtration, the unsealed surgical mask, cloth masks and face veils showed comparable performance and acceptable protection at the 5 μm particle size which is the most relevant to COVID-19 infectious droplets. Under the experimental conditions, wearing a surgical mask under the face veil significantly improves the FE compared to wearing a face veil alone.

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