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# Comparison of Filtration Efficiency and Pressure Drop in Anti-Yellow Sand Masks, Quarantine Masks, Medical Masks, General Masks, and Handkerchiefs

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## ABSTRACT

Particulate respirators have been used in both general environments and in the workplace. Despite the existence of certified respirators for workers, no strict regulations exist for masks worldwide. The aims of this study were to evaluate the filter efficiency of various mask types using the Korean Food and Drug Administration (KFDA) [similar to the European Union (EU) protocol] and the National Institute for Occupational Safety and Health (NIOSH) protocol and to compare the test results. We tested a total of 44 mask brands of four types (anti-yellow sand, medical, quarantine, general) and handkerchiefs with a TSI 8130 Automatic Filter Tester. A wide variation of penetration and pressure drops was observed by mask types. The overall mean penetration and pressure drop of all tested masks were respectively 35.6 ± 34.7%, 2.7 ± 1.4 mm $H_2O$ with the KFDA protocol, and 35.1 ± 35.7%, 10.6 ± 5.88 mm $H_2O$ with the NIOSH protocol. All tested quarantine masks satisfied the KFDA criterion of 6%. Six-ninths and four-sevenths of the anti-yellow sand masks for adults and children satisfied the criterion of 20%, respectively. Medical masks, general masks, and handkerchiefs were found to provide little protection against respiratory aerosols.

***Keywords:*** Respirator; Penetration; KFDA; NIOSH.

## INTRODUCTION

Recently, many events have transpired related to hazardous air pollutants such as yellow-sand dust, foot-and-mouth disease, and avian influenza in Asia and other regions. Personal protective equipment (PPE) is often regarded to be a last resort measure after substitution, isolation, and ventilation in occupational hygiene areas. However, ordinary citizens use masks and even handkerchiefs as first-protection devices against the inhalation of external harmful substances such as influenza particles and dust. These masks and handkerchiefs are used with the belief that they protect the wearer. They vary widely in style, and can be found in a broad range of market, hospital, and health-care settings (Lai *et al.*, 2012). For example, seeing people wearing masks during influenza episodes, the yellow-sand dust season (i.e., spring in the East Asian region) and in hospitals (both patients and health-care workers) is not uncommon. Yellow sand occurs in the loess area of northern China and is known to affect the air quality of China, Korea, Japan, and Taiwan (Kang *et al.*, 2004; Zhang *et al.*, 2010; Chao *et al.*, 2012). The number and degree of dust phenomenon events is increasing (Kim and Kim, 2003).

Since the outbreaks of severe acute respiratory syndrome (SARS) in Asia that spread over approximately 30 countries, viruses have gained additional attention worldwide. Viruses in the air, such as SARS and foot-mouth disease, can cause inflammation of the lungs via inhaled droplets generated and spread from the nose or mouth (Nassiri, 2003; Wang *et al.*, 2004; Lee *et al.*, 2008).

Since respirators were developed, many studies on the degree of penetration, pressure drop, and face leakage of respirators for the workplace have been conducted, but few studies on masks for general citizens were conducted until recently.

Some studies tested a limited number of N95 respirator

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models and observed higher than 5% penetration. Six respirators (models N95, N99, R95, P100) were dipped in isopropanol for 15 s and allowed to dry. This isopropanol dip should reduce or eliminate any electrostatic charge on the fibers of each filter. So, the penetration of six degraded respirators were reduced to 5% and over (Martin Jr and Moyer, 2000). The performance of two model N95 respirators against nano-sized particles was evaluated at two inhalation flow rates, 30 and 85 L/min. At 30 and 85 L/min, the respirators showed less than 5% and above 5% penetration, respectively, of nanoparticles (Balazy *et al.*, 2006b). Two N99 and one N95 respirators exposed to a sodium chloride (NaCl) aerosol and three virus aerosols (enterobacteriophages MS2, T4, and *Bacillus subtilis* phage) were examined on manikins using three inhalation flow rates (30, 85, and 150 L/min). All respirators used in this study satisfied the criteria of N95 and N99 at both 30 and 85 L/min using the NaCl and virus, but neither respirator did so at 150 L/min. Filter penetration of the tested biological aerosols did not exceed that of the inert NaCl aerosol (Eninger *et al.*, 2008). Rengasamy *et al.* (2008) investigated the filtration performance of N95 and P100 respirators against six different monodisperse silver aerosol particles in the range of 4–30 nm diameter at 85 L/min. The data from this study confirmed that the N95 and P100 respirators provided filtration performances of greater than 95% and 99.97%, respectively.

In hospitals, the roles of masks for the protection of medical staff from the patient or the protection of patients from medical staff are controversial (Abramson, 1944; Grinshpun *et al.*, 2009; Johnson *et al.*, 2009; Diaz and Smaldone, 2010). Medical masks have been used to block blood and other droplets during patient handling and operations. However, their filtration efficiencies have not been validated for small aerosol droplets. Seeing people block their mouths and noses with handkerchiefs during dusty conditions is not uncommon (van der Sande *et al.*, 2008; Jefferson *et al.*, 2009; Lai *et al.*, 2012). Balazy *et al.* (2006a) conducted experiments using two types of N95 half-mask respirators and two types of surgical masks exposed to aerosolized MS2 virus. N95 half-mask respirators may not provide proper protection against viruses, which are considerably smaller than the accepted smallest particle penetration size (300 nm) used in the certification tests, and some N95 respirators may fall below 95%. The efficiency of the surgical masks is much lower than that of the N95 respirators.

One large prospective randomized control trial reported on general surgical patients. Half the group underwent operations during which the surgical team used masks, and in the other half, masks were not used. No significant difference was observed in the infection rate, and the bacteria that were subsequently cultured did not differ between the two groups. Indeed, a trend for more infections to occur was noted in the group wearing masks (Tunevall and Bessey, 1991; Taylor and Reidy, 1998). Another study suggested that surgical masks worn by potentially infectious individuals may effectively contain exhaled aerosols, offering protection to those around them (Fennelly, 1998; Siegel *et al.*, 2007; Johnson *et al.*, 2009).

To verify the performance of the respirator used in the workplace, the European Union (EU) and National Institute for Occupational Safety and Health (NIOSH) protocols are typically used worldwide. In the European Union, the minimum efficiencies for filtering facepieces P1 (FFP1) and P1, and FFP2 and P2 products are 80% and 94%, respectively. For FFP3 respirators, the minimum filtration efficiency is 99%, while for P3 filters, the value is 99.95% (Howie, 2008). In Korea, since the EU standard was adopted, the efficiency requirements specified by the Korea Ministry of Labor (KMOL) for Second, First, and Special series are the same as the European requirements for FFP1/P1, FFP2/P2, and FFP3/P3, respectively (Cho *et al.*, 2011).

In the United States, the NIOSH tests and certifies 95, 99, and 100 series particulate filters and respirators, with minimum required filtration efficiencies of 95%, 99%, and 99.97%, respectively. Certification of respirators with test methods for measuring filtration efficiency in these standards vary with the type of aerosol and are designated by N (not resistant to oil), R (somewhat resistant to oil), and P (strongly resistant, oilproof) (NIOSH, 1996; Moyer and Bergman, 2000; Rengasamy *et al.*, 2011).

Unlike respirators for workers, which must be tested and certified by strict standards set by the NIOSH in the United States and the Korean Occupational Safety and Health Agency (KOSHA) in Korea, no strict regulations have been established for the filtration efficiency and pressure drop for medical (surgical/dental), quarantine, and general masks worldwide, and no data exist on the filtration efficiency of handkerchiefs.

Little data have been published on the effectiveness of these masks, but the number of wearers is rapidly increasing and many people are concerned about mask protection efficiency. The purpose of this study was to evaluate the filtration efficiency and pressure drop of various types of approved and non-approved masks using the Korean Food and Drug Administration (KFDA) (similar to EU test protocol) test protocol and the NIOSH test protocol and to compare the results. Other aspects for respirator selection such as fit test, total leakage during mask use, and comfort of the respirator on the face were not addressed in this study.

## METHODS

### *Study Design*

After visiting several pharmacy stores, searching e-markets on the Internet, and consulting with several health-care workers, we selected a total of 44 different models. Among them, 22 models were approved by the KFDA and/or the NIOSH, other 19 masks were non-approved but commercially available and 3 handkerchiefs were tested for this study. Nine adults and seven children's anti-yellow dust mask brands were chosen. In addition, nine quarantine masks, seven medical masks (four surgical, three dental), nine general masks, and three handkerchiefs were tested (Table 1).

Medical (surgical/dental) masks were tested in both airflow directions: an inward test (from the outer air to the

**Table 1.** General Information of mask type.

| No. | Type | | Approved Class | | Material of respirator | Shape |
|---|---|---|---|---|---|---|
| | | | KFDA | NIOSH | | |
| 1 | Yellow sand | Adult | KF80 | - | Nonwoven | Flat |
| 2 | | | KF80 | - | Nonwoven | Flat |
| 3 | | | KF80 | - | Nonwoven | Flat |
| 4 | | | KF80 | - | Nonwoven | Flat |
| 5 | | | KF80 | - | Cotton | Flat |
| 6 | | | KF80 | - | Cotton | Flat |
| 7 | | | KF80 | - | Cotton | Flat |
| 8 | | | KF80 | N95 | Nonwoven | Flat |
| 9 | | | KF80 | N95 | Nonwoven | Flat |
| 10 | | Child | KF80 | - | Nonwoven | Flat |
| 11 | | | KF80 | - | Nonwoven | Flat |
| 12 | | | KF80 | - | Nonwoven | Flat |
| 13 | | | KF80 | - | Nonwoven | Flat |
| 14 | | | - | - | Cotton | Flat |
| 15 | | | - | - | Cotton | Flat |
| 16 | | | - | - | Nonwoven | Flat |
| 17 | Quarantine | | KF94 | - | Nonwoven | Flat |
| 18 | | | KF94 | - | Nonwoven | Flat |
| 19 | | | KF94 | - | Nonwoven | Cup |
| 20 | | | KF94 | - | Nonwoven | Flat |
| 21 | | | - | N95 | Nonwoven | Cup |
| 22 | | | KF80 | N95 | Nonwoven | Cup |
| 23 | | | - | N95 | Nonwoven | Flat |
| 24 | | | - | N95 | Nonwoven | Cup |
| 25 | | | - | N95 | Nonwoven | Cup |
| 26 | Medical | Surgical | - | - | Cotton | Flat |
| 27 | | | - | - | Nonwoven | Flat |
| 28 | | | - | - | Nonwoven | Cup |
| 29 | | | - | - | Nonwoven | Cup |
| 30 | | Dental | - | - | Nonwoven | Flat |
| 31 | | | - | - | Nonwoven | Flat |
| 32 | | | - | - | Nonwoven | Flat |
| 33 | General | | - | - | Nonwoven | Flat |
| 34 | | | - | - | Nonwoven | Flat |
| 35 | | | - | - | Nonwoven | Flat |
| 36 | | | - | - | Nonwoven | Flat |
| 37 | | | - | - | Cotton | Flat |
| 38 | | | - | - | Cotton | Flat |
| 39 | | | - | - | Cotton | Flat |
| 40 | | | - | - | Cotton | Flat |
| 41 | | | - | - | Cotton | Flat |
| 42 | Handkerchief | | - | - | Cotton | - |
| 43 | | | - | - | Gauze | - |
| 44 | | | - | - | Towel | - |

mouth direction, mimicking inhalation) and an outward test (from the mouth to the outer air, mimicking exhalation). Handkerchiefs are not masks but are used in situations when people feel that dust is in the air. We therefore tested handkerchiefs in one to four layers separately.

Before testing the penetration and pressure drop, the tested aerosols were examined to meet the size criteria of the NIOSH and the KFDA with a scanning mobility particle sizer (SMPS, TSI-3910; TSI Inc., Shoreview, MN, USA).

***NaCl and Paraffin Oil Test***

Two TSI 8130 Automatic Filter Testers (AFTs) were used for NaCl initial and loading tests, and for paraffin oil quarantine mask initial tests. These two instruments were designed in compliance with the KFDA protocol and NIOSH Regulation 42 CFR Part 84 protocols, respectively. Initial test was run to estimate the value of penetration at the beginning of experiment within 1 minute and the loading test was done to evaluate the change of respirators pressure drop until a mass of 200 mg of NaCl or paraffin oil aerosol was accumulated on the test filters (Cho *et al.*, 2011). In some cases, the test was stopped earlier due to the high pressure drop.

The samples were attached to plates with hot-melt adhesive. When we were testing on the TSI 8130 automated filter tester (AFT), the plate was placed into the lower chuck of the tester. A spacer ring (20 cm diameter and 10 cm height) fitted with a gasket was placed on top of the sample holder, and a second plate was placed on top of the spacer ring. When the AFT chucks were closed, the pressure of the top chuck on the upper plate compressed the plates and spacer ring together to form an airtight seal. The TSI instrument is based on the measurement of the flux of scattered light. It uses two aerosol photometers to measure the particle penetration, with one placed before and one after the filter (NIOSH, 1996; TSI, 2006). The photometer output signals were approximately proportional to the aerosol mass and used to calculate filter penetration P as

$$P(\%) = \frac{C_{down}}{C_{up}} \times 100, \quad (1)$$

where $C_{down}$ is the aerosol concentration downstream of the respirator filter and $C_{up}$ is the challenge aerosol concentration upstream of the respirator filter. Tests using NaCl and paraffin oil aerosols were conducted according to KFDA and NIOSH protocols for filter penetration, with two exceptions. The samples were not preconditioned at 38°C and 85% relative humidity (RH) for 24 h prior to testing. Preconditioning might have been appropriate if all the products were KFDA- and NIOSH-certified. However, given that some of the products were not specifically designed to meet the KFDA and NIOSH preconditioning requirement, it was omitted from our test protocol. This approach is supported by the observation of Moyer and Stevens (1989), who in discussing the effect of humidity on filter efficiency, stated that "the effect of particle charge and size is significantly larger than the effect of RH." This abbreviated test procedure (e.g., no preconditioning) provides results similar to those from longer NIOSH certification tests (Viscusi *et al.*, 2009; Rengasamy *et al.*, 2011). To conduct filter tests using the KFDA method, the adopted EU method was similar to the NIOSH method, with the exception that the challenging NaCl concentration was 1%, with a flow rate of 95 L/min for initial penetration, and a loading test and 30 L/min for the initial pressure drop test.

NaCl was selected because it is commonly used in many respirator certification standards. Additionally, for the quarantine mask, we also evaluated the penetration using paraffin oil with a flow rate of 95 L/min. This was to test the oily mists according to the KFDA protocol. They were used to simulate oily mists, not solid particles. For the NIOSH protocol, a 2% NaCl solution was prepared with distilled water as specified by the TSI to obtain an aerosol with a count median diameter (CMD) of 75 ± 20 nm and geometric standard deviation (GSD) of ≤ 1.86. The aerosol was neutralized to the Boltzmann equilibrium charge distribution by injecting positive and negative ions from electrically pulsed tungsten needles into a dilution airstream that was mixed with the aerosol. A constant flow rate of 85 L/min was applied to the respirator and masks.

Most respirator standards also contain test methods for measuring breathing resistance through the respirator. Inhalation and/or exhalation resistance are measured at a given airflow rate using a pressure gauge. These measurements may be made separately from or during the filtration efficiency testing. Penetration can be measured as low as 0.001% and with pressure drops up to 150 mm $H_2O$. The penetration and pressure drop were recorded at about 1-min intervals throughout the test. Six samples of each model were tested: three for the KFDA method and three for the NIOSH method.

### *Statistical Analysis*

All data on penetration and pressure drop values were analyzed using arithmetic mean values. According to the European standard for respirators, the penetration and pressure drop values of tested respirators should be analyzed using the arithmetic mean value (EN136, 1998; EN140, 1998). Using a *t*-test, we analyzed the difference in penetration and pressure drops of approved and non-approved anti-yellow sand masks for children and quarantine masks, inward (from the outside air to the mouth direction) or outward (from the mouth to the outside air direction). ANOVA tests were used for differences in the type of mask and handkerchief fold. To compare with the KFDA and NIOSH protocols, we used a paired *t*-test. All analyses used SAS for Windows 9.3 (SAS Institute Inc., Cary, NC, USA) at $\alpha = 0.05$.

## RESULTS

### *Particle Size Distribution of NaCl and Paraffin Oil Aerosol*

Fig. 1 shows the size distribution of the NaCl and paraffin oil aerosol particles measured by a SMPS. We used the same testing equipment that was found to satisfy the NIOSH NaCl aerosol specification, as published previously (Cho *et al.*, 2011). The average CMD of the NaCl aerosol was 77.9 nm with the KFDA protocol, which matched the target CMD for the KFDA protocol closely. The average GSD was 1.95, which was well within the KFDA specifications. The CMD was 224.9 nm (GSD 2.15) for paraffin oil aerosols with the KFDA protocol.

### *Penetration*

The results of the initial penetration with NaCl aerosols are presented in Table 2. The data in the Table include the average reading for the three samples and the associated standard deviation in the format "x.xxx ± x.xxx" (Cho *et al.*, 2011). A wide variation of penetration values was observed with mask type. As seen in Table 2, the lowest average penetration was measured in the quarantine mask. This was followed in order by the adult anti-yellow sand mask, the child anti-yellow sand mask, the medical mask, the general mask, and the handkerchief. No significant difference in penetration was noted between the KFDA (similar to EU) protocol and the NIOSH protocol ($p = 0.12$). However, the penetration value was significantly different between mask types ($p < 0.001$ in both the KFDA and NIOSH protocols).

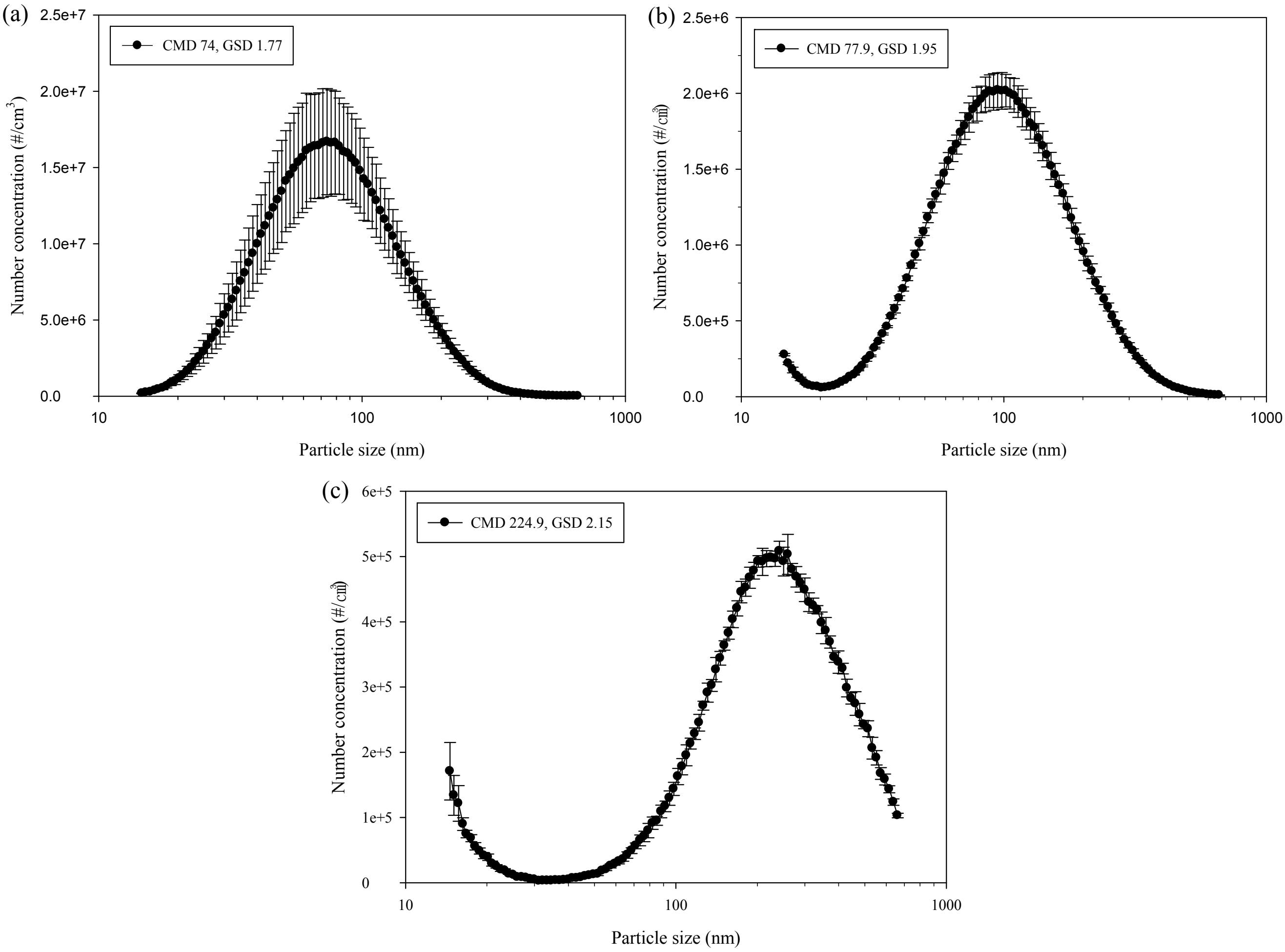


**Fig. 1.** Size distribution of sodium chloride aerosols measured by a scanning mobility particle sizer (SMPS). (a) Number concentration of NaCl aerosols tested by the NIOSH protocol. (b) Number concentration of NaCl aerosols tested by the EU protocol. (c) Number concentration of paraffin oil aerosols.

**Table 2.** Initial penetration using KFDA (similar to EU) protocol and NIOSH protocol by mask types (PN: Penetration).

| Mask classification | N | Initial PN (%) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | KFDA | | | | NIOSH | | | | P value‡ |
| | | Mean | ± | SD | P value* | Mean | ± | SD | P value† | |
| Yellow sand mask for adult | 9 | 15.119 | ± | 16.542 | | 12.640 | ± | 14.506 | | |
| Yellow sand mask for children | 7 | 23.681 | ± | 19.459 | | 37.031 | ± | 25.518 | | |
| Quarantine mask[a] | 9 | 0.864 | ± | 0.754 | | 0.585 | ± | 0.532 | | |
| Quarantine mask[b] | 9 | 2.057 | ± | 0.300 | < 0.0001 | | - | | < 0.0001 | 0.1223 |
| Medical mask | 7 | 44.695 | ± | 34.844 | | 43.641 | ± | 35.671 | | |
| General mask | 9 | 62.359 | ± | 23.548 | | 63.093 | ± | 26.243 | | |
| Handkerchief | 3 | 97.567 | ± | 2.071 | | 97.033 | ± | 3.173 | | |

[a] KFDA test for quarantine masks using sodium chloride.
[b] KFDA test for quarantine masks using paraffin oil.
* P value between mask types using KFDA method (except quarantine masks test result using paraffin oil).
† P value between mask types using NIOSH method.
‡ P value between KFDA and NIOSH test methods (except quarantine masks test result using paraffin oil).

The initial penetration values of anti-yellow sand masks for adults were 15.1 ± 16.5% and 12.6 ± 14.5% with the KFDA and NIOSH protocols, respectively, satisfying the KFDA anti-yellow-sand mask criterion of 20% penetration (KF 80). The penetration value of the yellow sand mask for children was 23.7 ± 19%, which was over the KFDA criteria of 20% for the anti-yellow sand mask. KFDA does not specify a criterion for children so we compared this with the KF 80 value. When we tested with the NIOSH protocol, the penetration value for the child anti-yellow sand masks was 37.03 ± 25.5%, which was very different from the KFDA test result.

All quarantine masks showed low penetration among the tested mask types, with a value of 0.9 ± 0.8% using the KFDA protocol and 0.6 ± 0.5% using the NIOSH protocol, satisfying criteria of the KFDA (KF 94). The penetration values of medical (surgical/dental) masks were over 40% and those of general masks exceeded 60%. All of these masks seemed to have little protection function against test aerosols. Handkerchiefs showed more than 98% initial penetration regardless of the material (cotton or gauze), and more than 87% for a folded status (Table 3 shows each value for one, two, three, and four layers), which means that handkerchiefs had no protection function against tested aerosols.

Table 3 shows the initial penetration classified by several characteristics of the tested masks. For children's use anti-yellow sand masks, a significant difference in penetration was observed between certified (KF 80) and noncertified masks ($p < 0.001$ with the KFDA protocol, $p = 0.003$ with the NIOSH protocol, respectively). The average penetration of certified and noncertified masks was 12.5 ± 10.1%, 38.6 ± 19.2% with the KFDA protocol and 23.7 ± 22.8%, 54.8 ± 17.0% with the NIOSH protocol, respectively. In Korea, the KFDA has a penetration criterion for anti-yellow sand masks and quarantine masks with maximum penetration of 20% (KF 80) and 6% (KF 94), respectively. Six of nine anti-yellow sand masks (67%) and four of seven children's anti-yellow sand masks (57%) satisfied the KF 80 criteria, and all quarantine masks satisfied the KF 94 criteria.

For quarantine masks using NaCl, certified masks with criteria of 6% penetration (KF 94) showed 0.62% and 0.37% penetration with the KFDA and NIOSH protocols, respectively. No significant difference was observed between test protocols ($p = 0.068$). Noncertified quarantine masks also met the KF 94 criteria, with a penetration of 1.06% using the KFDA protocol and 0.76% using the NIOSH protocol. These values were slightly higher than those for the certified quarantine masks. The values of the certified and noncertified quarantine masks using paraffin oil were 1.67% and 2.34%, respectively. Hence, the certified masks also showed better filter performance than noncertified masks using both NaCl and paraffin oil test aerosols.

In the case of medical masks, the penetration of dental masks was less than the penetration of surgical masks, but all of them showed over 20% penetration. The test results for inward and outward flow showed no significant difference (i.e., $p = 0.993$, 0.439 for the surgical and dental masks with the KFDA protocol, respectively, and $p = 0.946$, 0.731 for surgical and dental masks with the NIOSH protocol, respectively).

**Table 3.** Initial penetration classified by several characteristics of masks (PN: Penetration).

| Mask classification | | Variables | N | Initial PN (%) KFDA Mean ± SD | KFDA P value* | NIOSH Mean ± SD | NIOSH P value† | P value‡ |
|---|---|---|---|---|---|---|---|---|
| Yellow sand | Children | Certified (KF80) | 4 | 12.476 ± 10.072 | 0.0007 | 23.721 ± 22.840 | 0.0029 | 0.0005 |
| | | No Certified | 3 | 38.622 ± 19.174 | | 54.778 ± 17.046 | | |
| Quarantine[a] | | Certified (KF94) | 4 | 0.622 ± 0.362 | 0.1117 | 0.371 ± 0.272 | 0.0462 | 0.0679 |
| | | Not Certified[§] | 5 | 1.058 ± 0.929 | | 0.756 ± 0.631 | | |
| Quarantine[b] | | Certified (KF94) | 4 | 1.698 ± 1.111 | 0.2928 | - | - | - |
| | | Not Certified[§] | 5 | 2.344 ± 1.827 | | - | | |
| Medical | Surgical | Inward | 2 | 58.783 ± 36.215 | 0.9931 | 59.083 ± 36.707 | 0.9459 | 0.6330 |
| | | Outward | | 58.967 ± 35.794 | | 57.667 ± 33.724 | | |
| | Dental | Inward | 3 | 31.933 ± 12.605 | 0.4388 | 29.056 ± 11.963 | 0.7305 | 0.0353 |
| | | Outward | | 27.667 ± 10.050 | | 31.233 ± 14.288 | | |
| General | Nonwoven | - | 4 | 52.717 ± 10.422 | 0.0411 | 45.250 ± 9.414 | 0.0004 | 0.8153 |
| | Cotton | - | 5 | 70.073 ± 28.303 | | 77.367 ± 26.799 | | |
| Handkerchief | Cotton | One layer | 1 | 98.000 ± 0.346 | < 0.0001 | 98.933 ± 0.666 | 0.0013 | 0.0006 |
| | | Two layers | | 95.267 ± 0.666 | | 98.033 ± 0.702 | | |
| | | Three layers | | 91.233 ± 1.002 | | 96.867 ± 0.379 | | |
| | | Four layers | | 87.067 ± 0.737 | | 96.200 ± 0.346 | | |
| | Gauze | One layer | 1 | 99.567 ± 0.404 | 0.0069 | 99.300 ± 0.300 | < 0.0001 | 0.0138 |
| | | Two layers | | 99.033 ± 1.002 | | 98.633 ± 0.493 | | |
| | | Three layers | | 98.200 ± 0.500 | | 98.000 ± 0.400 | | |
| | | Four layers | | 97.200 ± 0.265 | | 96.367 ± 0.351 | | |

[a] KFDA test for quarantine masks using sodium chloride.
[b] KFDA test for quarantine masks using paraffin oil.
[*] P value between mask types using KFDA method (except quarantine masks test result using paraffin oil).
[†] P value between mask types using NIOSH method.
[‡] P value between KFDA and NIOSH test methods (except quarantine masks test result using paraffin oil).
[§] Not certified by KFDA but certified by NIOSH (N95 grade respirator).

General masks, regardless of their material, showed little protection against the tested aerosols, even when they had a fancy brand name (i.e., Best Nano, Ultra Antibiotic, Anytime Guard, Hygiene). The average penetration values of nine tested general masks were 62.4% with the KFDA protocol and 63.1% with the NIOSH protocol, respectively (Table 2). Nonwoven material showed about 50% penetration while masks made of cotton displayed over 70% penetration (Table 3). Handkerchiefs demonstrated very little protection against the tested aerosols. Penetration was over 95% when tested with the KFDA protocol, decreasing to 87–91% when three and four layers were used. More handkerchief layers meant less penetration, but the filtration effect was small even when a well-folded handkerchief was used.

Fig. 2 shows several examples of mask penetration patterns according to the mass loading of NaCl aerosol at the mask. The test masks were certified as KF 80 (maximum 20% penetration, product 9) or KF 94 (maximum 6% penetration, products 24, 25, and 27) class and were found to satisfy these criteria in this study. Penetration values were interpolated from the raw data at regular aerosol load intervals (10 mg, 20 mg,…) from each load test to permit averaging of the results for the three samples of each type. The error bars represent ± 1 SD.

As seen in Fig. 2, the shapes of the penetration curves are similar between the KFDA and NIOSH test protocols within the same products, although the patterns are somewhat different between the products. For example, products 25 and 27 showed a significant increase in penetration before decreasing, while products 9 and 24 displayed a decreasing pattern according to the NaCl aerosol loading. Nevertheless, they all remained well below the certification limit of 20% for anti-yellow sand mask penetration and 6% for quarantine mask penetration.

***Pressure Drop***

The results of the pressure drop are summarized in Table 4. The pressure drop showed little variation compared to the penetration in Table 2. The average pressure drops of all tested masks were 2.73 ± 1.44 (range 0.4–9.5) $mmH_2O$ with the KFDA protocol and 10.55 ± 5.87 (range 0.6–26.3) $mmH_2O$ with the US NIOSH protocol (data not shown). When tested using the KFDA protocol, the highest pressure drop was measured in the anti-yellow sand mask for adults (3.34 ± 2.20 $mmH_2O$), followed by the quarantine mask, the children's anti-yellow sand mask, the medical (surgical/dental) mask, the general mask, and the handkerchief. The pressure drops of all tested masks were below the criterion of 7.2 $mmH_2O$ (KF 94 class) and 6.2 $mmH_2O$ (KF 80 class). When using the NIOSH protocol, we found that the pressure drop for anti-yellow sand masks was the highest (13.67 ± 5.23 $mmH_2O$) and all masks except the handkerchief were over the KF 80 and 94 pressure limits. As expected, the pressure drop of the handkerchief was lowest (1.90 $mmH_2O$), while its penetration was over 97%.

Table 5 shows the pressure drop classified by several characteristics of the tested masks. For children, we used anti-yellow sand masks. No significant difference was observed in the pressure drop between certified (KF 80) and noncertified masks ($p = 0.910$ with the KFDA protocol, $p = 0.653$ with the NIOSH protocol, respectively). However, a significant difference was detected in the pressure drop between test protocols ($p < 0.001$). In the case of quarantine masks, significant differences were detected in the pressure drop between certified (KF94) and noncertified masks ($p = 0.0218$ with the KFDA protocol and $p = 0.0016$ with the NIOSH protocol, respectively) and between test protocols ($p < 0.001$). No significant differences were observed in pressure drop when medical (surgical/dental) masks were tested inward (from the outside air to the mouth) or outward (from the mouth to the outside air), or for the composition of the general masks. The pressure drops of the handkerchiefs increased significantly with the number of layers ($p = 0.001$), but all values were less than 4 $mmH_2O$.

Fig. 3 shows the mask pressure drop patterns for the masks, which were similar between the KFDA and NIOSH

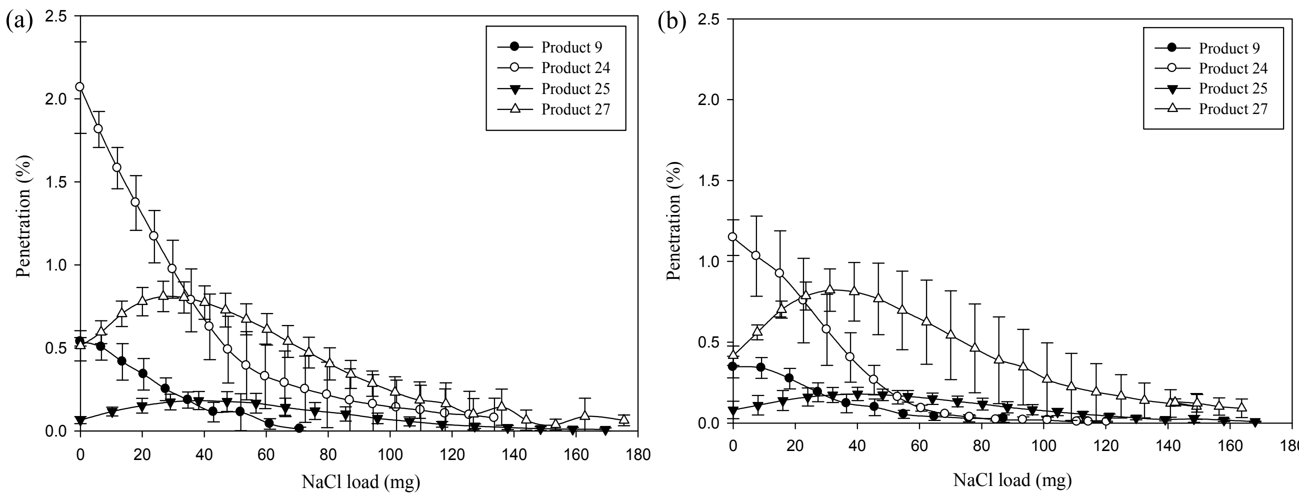


**Fig. 2.** Penetration as a function of NaCl aerosol accumulation on the mask using the KFDA protocol (a) and NIOSH protocol (b). Symbols represent mean values and vertical lines represent 1 SD of the results from the three tests conducted for each mask.

**Table 4.** Initial pressure drop using KFDA (similar to EU) protocol and NIOSH protocol by mask types (PD: Pressure drop).

| Level of class | N | Initial PD ($mmH_2O$) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | KFDA | | | | NIOSH | | | | P value‡ |
| | | Mean | ± | SD | P value* | Mean | ± | SD | P value† | |
| Yellow sand mask for adult | 9 | 3.341 | ± | 2.198 | 0.0143 | 13.665 | ± | 5.298 | < 0.0001 | < 0.0001 |
| Yellow sand mask for children | 7 | 2.881 | ± | 0.866 | | 12.140 | ± | 4.675 | | |
| Quarantine mask | 9 | 3.037 | ± | 1.306 | | 12.461 | ± | 6.942 | | |
| Medical mask | 7 | 2.386 | ± | 0.811 | | 9.214 | ± | 3.703 | | |
| General mask | 9 | 2.244 | ± | 0.788 | | 8.215 | ± | 4.513 | | |
| Handkerchief | 3 | 1.878 | ± | 1.851 | | 1.889 | ± | 1.621 | | |

* P value between mask types using KFDA method.
† P value between mask types using NIOSH method.
‡ P value between KFDA and NIOSH test methods.

**Table 5.** Initial pressure drop value classified by several characteristics of masks (PD: Pressure drop).

| Variables | | | N | Initial PD ($mmH_2O$) | | | | | | | | P value‡ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | KFDA | | | | NIOSH | | | | |
| | | | | Mean | ± | SD | P value* | Mean | ± | SD | P value† | |
| Yellow sand | Child | Certified (KF80) | 4 | 2.858 | ± | 0.188 | 0.9102 | 11.729 | ± | 3.710 | 0.6534 | < 0.0001 |
| | | No Certified | 3 | 2.911 | ± | 1.351 | | 12.689 | ± | 5.926 | | |
| Quarantine | | Certified (KF94) | 4 | 3.667 | ± | 1.413 | 0.0218 | 17.458 | ± | 7.495 | 0.0016 | < 0.001 |
| | | Not Certified§ | 5 | 2.533 | ± | 0.993 | | 8.463 | ± | 2.616 | | |
| Medical | Surgical | Inward | 2 | 2.667 | ± | 0.137 | 0.2828 | 9.283 | ± | 1.087 | 0.0845 | < 0.0001 |
| | | Outward | | 2.583 | ± | 0.117 | | 13.283 | ± | 4.546 | | |
| | Dental | Inward | 3 | 2.633 | ± | 0.187 | 0.7198 | 11.033 | ± | 2.194 | 0.8484 | < 0.0001 |
| | | Outward | | 2.600 | ± | 0.200 | | 10.844 | ± | 1.922 | | |
| General | Nonwoven | - | 4 | 2.508 | ± | 0.999 | 0.1542 | 10.008 | ± | 5.112 | 0.0633 | < 0.0001 |
| | Cotton | - | 5 | 2.033 | ± | 0.512 | | 6.780 | ± | 3.511 | | |
| Handkerchief | Cotton | One layer | 1 | 0.800 | ± | 0.100 | < 0.0001 | 1.000 | ± | 0.000 | < 0.0001 | 0.1935 |
| | | Two layers | | 1.400 | ± | 0.100 | | 1.767 | ± | 0.058 | | |
| | | Three layers | | 2.933 | ± | 0.058 | | 2.700 | ± | 0.200 | | |
| | | Four layers | | 3.433 | ± | 0.058 | | 3.567 | ± | 0.252 | | |
| | Gauze | One layer | 1 | 0.500 | ± | 0.100 | < 0.0001 | 0.667 | ± | 0.058 | < 0.0001 | 0.0164 |
| | | Two layers | | 1.733 | ± | 0.153 | | 1.200 | ± | 0.000 | | |
| | | Three layers | | 2.667 | ± | 0.153 | | 1.967 | ± | 0.058 | | |
| | | Four layers | | 2.967 | ± | 0.058 | | 2.800 | ± | 0.173 | | |

* P value between mask types using KFDA method.
† P value between mask types using NIOSH method.
‡ P value between KFDA and NIOSH test methods.
§ Not certified by KFDA but certified by NIOSH (N95 grade respirator).

protocols. In all cases, the pressure drop increased over time due to particle loading on the filter, although a wide range was observed in the rates of increase.

## DISCUSSION

The aims of this study were to evaluate the filtration efficiency and pressure drop of various types of masks used by ordinary citizens or health-care workers, and to compare the test results using the KFDA and NIOSH protocols. We found that penetration was not significantly different between the KFDA and NIOSH protocols ($p = 0.122$), but the pressure drop using the KFDA protocol was significantly lower than that using the NIOSH protocol ($p < 0.001$). The difference in pressure drop values for the KFDA and NIOSH protocols can be explained by the difference in flow rates between the two protocols. The KFDA protocol uses a flow rate of 30 L/min because a low ordinary citizen's breathing rate was assumed by the KFDA. Hence, a low flow rate of 30 L/min during the initial pressure drop test could have caused a significant low pressure drop. The 1% NaCl aerosol solution in the KFDA (EU protocol) compared to the 2% NaCl solution of the NIOSH protocol could have affected the low pressure drop, but it appeared low because the initial pressure drop was measured during the first 1 min.

The filter efficiency of quarantine masks was the greatest, while that of handkerchiefs and general masks was the lowest. Of the 44 products studied, including three handkerchiefs,

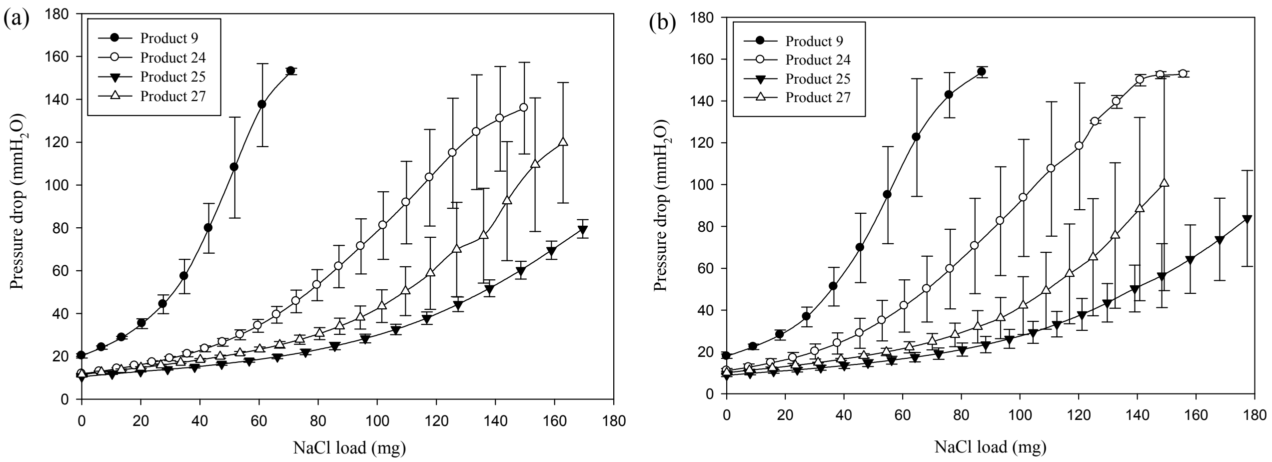


**Fig. 3.** Pressure drop as a function of NaCl aerosol accumulation on the mask using the KFDA (a) and NIOSH (b) protocols. The symbols represent mean values and the vertical lines represent 1 SD for the results from the three tests conducted for each mask. The pressure drop test in (a) and (b) were done at 95 L/min.

seven (16%) products (6 quarantine masks and 1 anti-yellow sand mask) using the KFDA protocol and 10 (22%) products (7 quarantine masks and 3 anti-yellow sand masks) using the NIOSH protocol were within 1% penetration (i.e., FFP 3 under the EU criterion or N99 under the NIOSH criterion) (Fig. 4). All these were certified with at least one of the KF 80 or 94 classes in Korea or the N95 class in the United States. Sixteen (36%) products using the KFDA protocol met the KF 94 criterion, 21 (47%) products met the KF 80 criterion, and 17 (39%) met the N95 criterion. Our results suggest that general masks and handkerchiefs provide little protection against airborne aerosols.

Three of four certified and one of three noncertified children's masks satisfied the KF 80 criterion, with average penetration of 9.9 ± 7.9%. The average penetration of failed children's masks was 42.1 ± 16.3%. Another study showed that when children wore the masks for adults, they were significantly less-protected from exposure than the adults. This might have been related to the inferior fit of the masks on their smaller faces (van der Sande *et al.*, 2008). The children's masks used in this study seemed to be simply adult masks that were reduced in size. As far as we know, no specific criteria for penetration and pressure drop exist for children's masks, even though their breathing volume, pattern, and rate are different from those of adults (Jammes *et al.*, 1979; Tabachnik *et al.*, 1981; Tobin *et al.*, 1983; Bennett and Zeman, 1998; Leigh *et al.*, 2006; Jung, 2008). Therefore, just reducing the mask size might not be a suitable strategy.

In this study, the penetration efficiency of medical masks ranged from 10% to 90%, except for one product (certified as a N95 class), which showed 1.82% penetration. Other studies also reported that penetration ranged from 10% to 47% in dental masks and 53% to 96% in surgical masks (Oberg and Brosseau, 2008). In this study, the penetration range of the dental mask was 16.8–47.9% with the KFDA protocol and 17.2–45.0% with the NIOSH protocol. For surgical masks, it was 1.56–98.0% with the KFDA protocol and 1.11–98.7% with the NIOSH protocol (data not shown).

In view of the possibility of airborne transmission, current guidelines issued by the Centers for Disease Control and Prevention (CDC) and the World Health Organization (WHO) state that health-care workers should wear N95 masks or higher-level protection during all epidemic situations (Derrick and Gomersall, 2005). However, no strict regulation exists for the filtration efficiency and pressure drop for surgical or dental masks worldwide. Penetration results using medical masks in this study exceeded the maximum KFDA criteria for anti-yellow sand masks of 80% (KF 80). In extreme cases for medical masks, the maximum penetration was almost 98%.

Our results show that the main determinant of the magnitude of protection was the type of mask. The expected superior protection conferred by a professional FFP2 mask compared to a surgical or homemade mask was maintained (van der Sande *et al.*, 2008). Leakage tests were performed on readily available materials such as cotton handkerchiefs or towels to measure the extent of penetration. Leakage fractions were determined by comparing the penetration of the same aerosol for the materials held to the face versus being fully taped to the face. At a breathing rate of 37 L/min, mean leakages for the materials ranged from 0.0% to 63%, depending on the material. Mean penetrations exclusive of leakage ranged from 0.6% to 39%. Use of nylon hosiery material ("panty hose") to hold the handkerchief material or the disposable face mask to the face was found to be very effective in preventing leakage (Cooper *et al.*, 1983b). Such a combination could be expected to reduce leakage around the handkerchief to about 10% or less in practice, and around the mask to less than 1.0%, which suggests that the adaptation and use of such an approach for industrial hygiene would be effective (Cooper *et al.*, 1983b). The fabrics provided a statistically nonsignificant reduction in methyl iodide. In practice, any leaks around the seal to the face would lessen the protection offered by such materials (Cooper *et al.*, 1983a). One study using modified heavyweight T-shirts similar to the 2-ply battle-dress uniform T-shirts showed that a hand-fashioned mask can provide a good fit

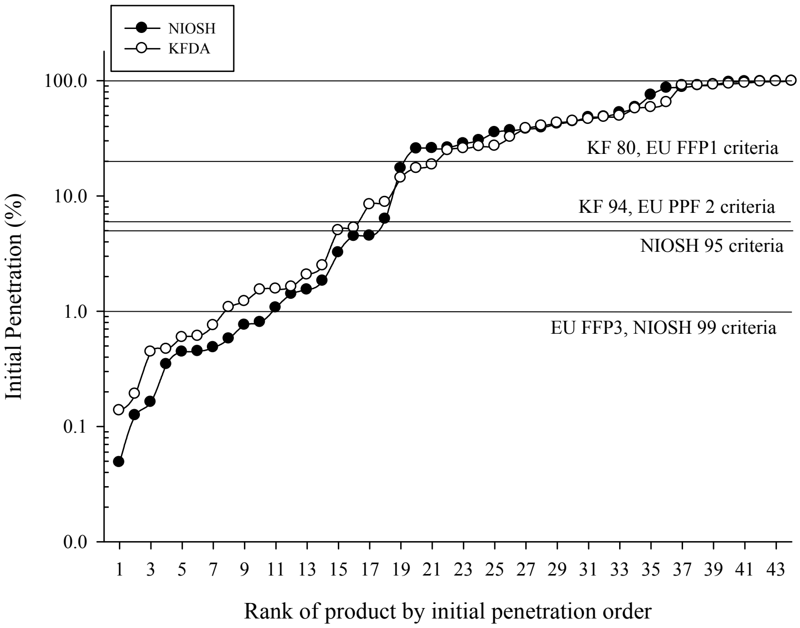


**Fig. 4.** Initial penetration of 41 tested masks and three handkerchiefs ranked by penetration order.

and a measurable level of protection from a challenge aerosol (Dato *et al.*, 2006). This T-shirt mask had three ear bands (tie type), but the ear bands of the general masks in the study had only two bands (fixation with elastic cord type) and no effects of electrostatic force were added. Therefore, when wearing a general mask, the possibility of penetration increases compared to respirators certified by government organizations.

We measured the initial penetration for 1 min and compared it with penetration criteria. However, as shown in Fig. 2, a slight increase in penetration could occur before a decline for a certain mask (i.e., products 25 and 27 in Fig. 2). In our previous study (Cho *et al.*, 2011; Cho and Yoon, 2012), we found that the initial penetration could be used to compare with the penetration criteria. The initial penetration levels have the advantage of avoiding any loading effects for better comparison with other testing methods (Viscusi *et al.*, 2009). The initial penetration measured for 1 min has been used in many studies in place of the entire NIOSH 42 CFR Part 84 test protocol (Stevens and Moyer, 1989; Lisowski *et al.*, 2001; Rengasamy *et al.*, 2009; Viscusi *et al.*, 2009; Cho *et al.*, 2011).

There are various national and international standards for testing and certifying particulate respirators (PRs) for workers. NIOSH protocol, EU protocol and Australia standard (AS/NZS 1715) are examples (Cho *et al.*, 2011). Unlike for worker's respirators, no national or international standards seem to exist for filtration efficiency and/or pressure drop in masks for ordinary citizens. KFDA recently promoted testing criteria for mask filtration efficiencies which was originated from EU standard. The maximum penetration value was 20% (KF 80) and 6% (KF 94) for anti-yellow sand and quarantine masks, respectively. The maximum pressure drop value was 6.5 $mmH_2O$ (KF 80) and 7.2 $mmH_2O$ (KF 94) for anti-yellow sand and quarantine masks, respectively. No criteria exist for penetration and pressure drops for medical and general masks in Korea and the United States. One could argue that both criteria (20% in KF 80, 6% in KF 94) are suitable to protect people against the corresponding aerosols because yellow-sand dust contains hazardous metals and microorganisms, while quarantine masks are used during epidemic events.

## CONCLUSION

We tested all 44 different brands of mask, including anti-yellow sand masks for adults and children, quarantine masks, medical masks, general masks, and handkerchiefs using the KFDA (similar to the EU protocol) and the NIOSH protocols. All tested quarantine masks satisfied the maximum penetration criterion of 6% (KF 94). Six of nine anti-yellow sand masks (67%) and four of seven anti-yellow sand masks for children (57%) satisfied the KF 80 criteria.

The penetration values of most medical masks were over 20%. Medical masks show no significant differences in penetration and pressure drop between inward tests (which mimic inhalation) and outward tests (which mimic exhalation). General masks and handkerchiefs have no protection function in terms of the aerosol filtration efficiency. No significant difference in penetration was noted between the KFDA and NIOSH protocols ($p$ = 0.1223), but the pressure drop using the KFDA protocol was significantly lower than that using the NIOSH protocol ($p < 0.001$). The government needs to prepare exact guidelines for mask use by citizens to avoid the inhalation of external harmful substances.

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## REFERENCES

Abramson, H. (1944). The Role of the Surgical Mask in the Prevention of Cross-Infections in Hospital Nurseries for Newborn Infants. *J. Pediatr.* 24: 684–690.

Balazy, A., Toivola, M., Adhikari, A., Sivasubramani, S.K., Reponen, T. and Grinshpun, S.A. (2006a). Do N95 Respirators Provide 95% Protection Level Against Airborne Viruses, and How Adequate Are Surgical Masks? *Am. J. Infect. Control* 34: 51–57.

Balazy, A., Toivola, M., Reponen, T., Podgorski, A., Zimmer, A. and Grinshpun S.A. (2006b). Manikin-Based Performance Evaluation of N95 Filtering-Facepiece Respirators Challenged with Nanoparticles. *Ann. Occup. Hyg.* 50: 259–269.

Bennett, W.D., Zeman K.L. (1998). Deposition of Fine Particles in Children Spontaneously Breathing at Rest. *Inhalation Toxicol.* 10: 831–842.

Chao, H.J., Chan, C.C., Rao, C.Y., Lee, C.T., Chuang, Y.C., Chiu, Y.H., Hsu, H.H. and Wu, Y.H. (2012). The Effects of Transported Asian Dust on the Composition and Concentration of Ambient Fungi in Taiwan. *Int. J. Biometeorol.* 56: 211–219.

Cho, H.W., Yoon, C.S., Lee, J.H., Lee, S.J., Viner, A. and Johnson, E.W. (2011). Comparison of Pressure Drop and Filtration Efficiency of Particulate Respirators Using Welding Fumes and Sodium Chloride. *Ann. Occup. Hyg.* 55: 666–680.

Cho, H.W. and Yoon, C.S. (2012). Workplace Field Testing of the Pressure Drop of Particulate Respirators Using Welding Fumes. *Ann. Occup. Hyg.* 56: 948–958.

Cooper, D.W., Hinds, W.C. and Price, J.M. (1983a). Emergency Respiratory Protection with Common Materials. *Am. Ind. Hyg. Assoc. J.* 44: 1–6.

Cooper, D.W., Hinds, W.C., Price, J.M., Weker, R. and Yee, H.S. (1983b). Common Materials for Emergency Respiratory Protection: Leakage Tests with a Mmanikin. *Am. Ind. Hyg. Assoc. J.* 44: 720–726.

Dato, V.M., Hostler, D. and Hahn, M.E. (2006). Simple Respiratory Mask: Simple Respiratory Mask. *Emerg. Infect. Dis.* 12: 1033–1034.

Derrick, J.L. and Gomersall, C.D. (2005). Protecting Healthcare Staff from Severe Acute Respiratory Syndrome: Filtration Capacity of Multiple Surgical Masks. *J. Hosp. Infect.* 59: 365–368.

Diaz, K.T. and Smaldone, G.C. (2010). Quantifying Exposure Risk: Surgical Masks and Respirators. *Am. J. Infect. Control* 38: 501–508.

EN136 (1998). European Committee for Standardization. Respiratory Protective Devices: Full-face Masks; Requirements, Testing, Marking.

EN140 (1998). European Committee for Standardization. Respiratory Protective Devices: Half-masks, Quarter-masks; Requirements, Testing, Marking.

Eninger, R.M., Honda, T., Adhikari, A., Heinonen-Tanski, H., Reponen, T. and Grinshpun, S.A. (2008). Filter Performance of N99 and N95 Facepiece Respirators against Viruses and Ultrafine particles. *Ann. Occup. Hyg.* 52: 385–396.

Fennelly, K.P. (1998). The Role of Masks in Preventing Nosocomial Transmission of Tuberculosis. *Int. J. Tubercul. Lung Dis.* 2: S103–S109.

Grinshpun, S.A., Haruta, H., Eninger, R. M., Reponen, T., McKay, R.T. and Lee, S.A. (2009). Performance of an N95 Filtering Facepiece Particulate Respirator and a Surgical Mask During Human Breathing: Two Pathways for Particle Penetration. *J. Occup. Environ. Hyg.* 6: 593–603.

Howie, R.M. (2008). Personal Protective Equipment, In *Occupational Hygiene*, Third Edition, Gardiner, K and Harrington, J.M (Eds.), Blackwell Publishing Ltd, Oxford, UK, doi: 10.1002/9780470755075.ch31, 2005: 461–472.

Jammes, Y., Auran, Y., Gouvernet, J., Delpierrre, S. and Grimaud, C. (1979). The Ventilatory Pattern of Conscious Man According to Age and Morphology. *Bull. Eur. Physiopathol. Respir.* 15: 527–540.

Jefferson, T., Del Mar, C., Dooley, L., Ferroni, E., Al-Ansary, L.A., Bawazeer, G.A., Van Driel, M.L., Foxlee, R. and Rivetti, A. (2009). Physical Interventions to Interrupt or Reduce the Spread of Respiratory Viruses: Systematic Review. *Br. Med. J.* 339: b3675

Johnson, D.F., Druce, J.D., Birch, C. and Grayson, M.L., (2009). A Quantitative Assessment of the Efficacy of Surgical and N95 Masks to Filter Influenza Virus in Patients with Acute Influenza Infection. *Clin. Infect. Dis.* 49: 275–277.

Jung, S.E. (2008). The Characteristics of Childhood Injuries Compared to Adult Injuries. *J. Korean Med. Assoc.* 51: 214–218.

Kang, K.K., Chu, J.M., Jeong, H.S., Han, W.J. and Yu, N. M. (2004) A Study on the Analysis of Damages of Northeast Asian Dust and Sand Storm and of the Regional Cooperation Strategies, Korea Environment Institute.

Kim, K.H. and Kim, M.Y. (2003). The Effects of Asian Dust on Particulate Matter Fractionation in Seoul, Korea during Spring 2001. *Chemosphere* 51: 707–721.

Lai, A.C., Poon, C.K. and Cheung, A.C. (2012). Effectiveness of Facemasks to Reduce Exposure Hazards for Airborne Infections among General Populations. *J. R. Soc. Interface* 9: 938–948.

Lee, S.A., Grinshpun, S.A. and Reponen, T. (2008). Respiratory Performance Offered by N95 Respirators and Surgical Masks: Human Subject Evaluation with NaCl Aerosol Representing Bacterial and Viral Particle Size Range. *Ann. Occup. Hyg.* 52: 177–185.

Leigh, S.B., Cheong, C.H., Lee, Y.G. and Kim, T.Y. (2006). Minimum Ventilation Rate of Kindergarten in the Respect of IAQ. *J. Air-Con. Refri. Eng.* 283–288.

Lisowski, A., Jankowska, E., Thorpe, A. and Brown, R. (2001). Performance of Textile Fibre Filter Material Measured with Monodisperse and Standard Aerosols. *Powder Technol.* 118: 149–159.

Martin Jr, S.B. and Moyer, E.S. (2000). Electrostatic Respirator Filter Media: Filter Efficiency and Most Penetrating Particle Size Effects. *App. Occup. Environ.*

*Hyg.* 15: 609–617.

Moyer, E.S. and Stevens, G.A. (1989). "Worst Case" Aerosol Testing Parameters: II. Efficiency Dependence of Commercial Respirator Filters on Humidity Pretreatment. *Am. Ind. Hyg. Assoc. J.* 50: 265–270.

Moyer, E.S. and Bergman, M.S. (2000). Electrostatic N-95 Respirator Filter Media Efficiency Degradation Resulting from Intermittent Sodium Chloride Aerosol Exposure. *App. Occup. Environ. Hyg.* 15: 600–608.

Nassiri, R. (2003). Severe Aacute Respiratory Syndrome. *Med. Sci. Monit. Int. Med. J. Exp. Clin. Res.* 9: ED25.

National Institure for Occupational Safety and Health (NIOSH) (1996). NIOSH Guide to the Selection and Use of Particulate Respirators Certified Under 42 CFR 84, DHHS (National Institute for Occupational Safety and Health). NIOSH, Cincinnati, OH, p. 96–101.

Oberg, T. and Brosseau, L.M. (2008). Surgical Mask Filter and Fit Performance. *Am. J. Infect. Control* 36: 276–282.

Rengasamy, S., King, W.P., Eimer, B.C. and Shaffer, R.E. (2008). Filtration Performance of NIOSH-approved N95 and P100 Filtering Facepiece Respirators against 4 to 30 Nanometer-size Nanoparticles. *J. Occup. Environ. Hyg.* 5: 556–564.

Rengasamy, S., Eimer, B.C. and Shaffer, R.E. (2009). Comparison of Nanoparticle Filtration Performance of NIOSH-approved and CE-marked Particulate Filtering Facepiece Respirators. *Ann. Occup. Hyg.* 53: 117–128.

Rengasamy, S., Miller, A. and Eimer, B.C. (2011). Evaluation of the Filtration Performance of NIOSH-approved N95 Filtering Facepiece Respirators by Photometric and Number-based Test Methods. *J. Occup. Environ. Hyg.* 8: 23–30.

Siegel, J.D., Rhinehart, E., Jackson M. and Chiarello, L. (2007). Guideline for Isolation Precautions: Preventing Transmission of Infectious Agents in Healthcare Settings, Healthcare Infection Control Practices Advisory Committee.

Stevens, G.A. and Moyer, E.S. (1989). Worst Case Aerosol Testing Parameters. 1. Sodium-Chloride and Dioctyl Phthalate Aerosol Filter Efficiency as a Function of Particle-size and Flow-rate. *Am. Ind. Hyg. Assoc. J.* 50: 257–264.

Tabachnik, E., Muller, N., Toye, B. and Levinson, H. (1981). Measurement of Ventilation in Children Using the Respiratory Inductive Plethysmograph. *J. Pediatr.* 99: 895–899.

Taylor, P.R. and Reidy, J.F. (1998). Surgical Face Masks: Are They Mandatory for Interventional Endovascular Procedures? *Cardiovasc. Inter. Rad.* 21: 448–449.

Tobin, M.J., Chadha, T. Jenouri, G., Birch, S., Gazeroglu H. and Sackner, M. (1983). Breathing Patterns. 1. Normal Subjects. *CHEST J.* 84: 202–205.

TSI, I., (2006). CertiTest® Model 8127/8130 Automated Filter Tester, In *Operation and Service Manual*, Revision, H, St Paul, Shoreview, MN.

Tunevall, T.G. and Bessey, P.Q. (1991). Postoperative Wound Infections and Surgical Face Masks - A Controlled-Study. *World J.Surg.* 15: 383–388.

van der Sande, M., Teunis, P. and Sabel, R. (2008). Professional and Home-Made Face Masks Reduce Exposure to Respiratory Infections among the General Population. *PLoS ONE* 3: e2618, doi: 10.1371/journal.pone.0002618.

Viscusi, D.J., Bergman, M., Sinkule E. and Shaffer, R.E. (2009). Evaluation of the Filtration Performance of 21 N95 Filtering Face Piece Respirators after Prolonged Storage. *Am. J. Infect. Control* 37: 381–386.

Wang, W. K., Chen, S.Y., Liu, I.J., Chen, Y.C., Chen, H.L., Yang, C.F, Chen, P.J., Yeh, S.H., Kao, C.L, Huang, L.M., Hsueh, P.R., Wang, J.T., Sheng, W.H., Fang, C.T., Hung, C.C., Hsieh, S.M., Su, C.P., Chiang, W.C, Yang, J.Y., Lin, J.H., Hsieh, S.C., Hu, H.P., Chiang, Y.P., Wang, J.T., Yang, P.C. and Chang S.C. (2004). Detection of SARS-associated Coronavirus in Throat Wash and Saliva in Early Diagnosis. *Emerg. Infect. Dis.* 10: 1213–1219.

Zhang, K., Chai, F., Zhang, R. and Xue, Z. (2010). Source, Route and Effect of Asian Sand Dust on Environment and the Oceans. *Particuology* 8: 319–324.

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