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Inhalation Resistance of Face Masks with Different Filtration Efficiencies and Designs at Various Flow Rates and Moisture Saturation

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Introduction

- At present, national guidelines recommend wearing masks as the most important factor to protect people from COVID-19. In many other countries, wearing a mask is obligatory for activities in public spaces including official meetings and participation in sports (Rensburg et al. 2020).
- However, wearing a mask reduces the amount of oxygen inhaled and can lead to a lack of oxygen in the brain, which may worsen the medical conditions of individuals with lung or heart diseases (Rensburg et al. 2020).
- The most critical factor determining the wearing comfort of a mask is breathing resistance, which consists of exhalation and inhalation resistance.
- Individuals who work at high intensities for 6 ~ 8 h for a day, or have underlying conditions such as respiratory diseases, chronic headaches, or are pregnant should consider the breathing resistance of certified face masks.

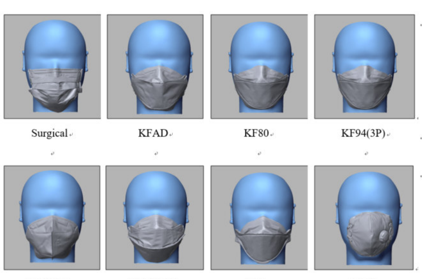
Purpose

To investigate the influential parameters for determining the inhalation resistance (IR) of face masks worn during the COVID-19 pandemic.

Methods

1. Disposable face masks chosen in the present study

Type	Design	Size	Band	Protection level (%)	Filter material	Inner/outer material	Dry mass (g)	Dead space (mm^3)	Surface area (cm^2)
Surgical	Pleats	L	Ear loop	≥65	MB PP†	SB PP‡	3.2	110,628	300
KFAD	Horizontal 3 panels	L	Ear loop		MB PP	SB PP	3.2	85,034	232
KF80	Horizontal 3 panels	L	Ear loop	≥80	MB PP	SB PP	4.2	106,627	219
KF94*	Horizontal 3 panels	L	Ear loop	≥94	MB PP	SB PP	4.4	106,627	219
	Vertical-fold flat 2 panels	L	Ear loop	≥94	MB PP	SB PP	4.3	86,066	234
	Horizontal 4 panels	L	Ear loo[	≥94	MB PP	SB PP	6.6	144,309	303
N95	Horizontal 3 panels	L	Head bands	≥95	MB PP	SB PP	8.9	145,924	276
KF99	Cup type/, Facial seal	L	Ear loop	≥99	MB PE§	SB PP	20.6	202,869	166
KF94**	Horizontal 3 panels	XS	Ear loo[	≥94	MB PP	SB PP		73,535	159
		S	Ear loop	≥94	MB PP	SB PP		90,722	179
		M	Ear loop	≥94	MB PP	SB PP		84,560	204
		L	Ear loop	≥94	MB PP	SB PP		103,365	213



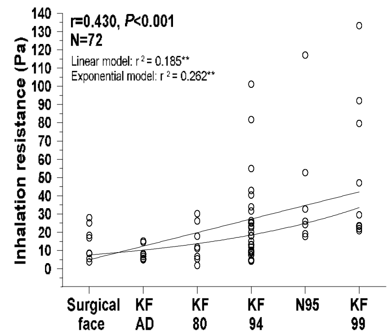
IR tester (ART-1651, ARTplus Co, Korea)

2. Measurements

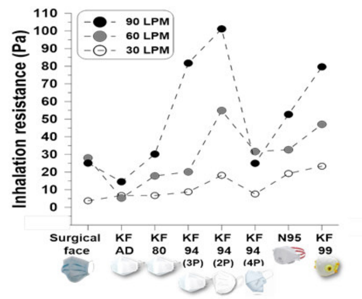
- Dead space between the head manikin and a mask inside : a 3D scanner (Handy BLACK Elite, Creaform, Canada)
- Surface area of a mask inside: Planimeter (X-plan 460 d III, Ushikata, Japan).
- Inhalation resistance (IR): A mask inhalation resistance tester with a human head mold (ARE-1651, ART Plus, Korea). Flow rate at 30, 60 and 90 LPM. A trial of 60 s was repeated three times and those values were averaged.

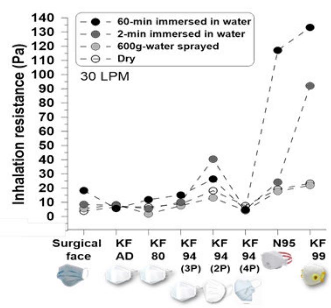
Results

1. Filtration efficiency, flow rate, and moisture saturation



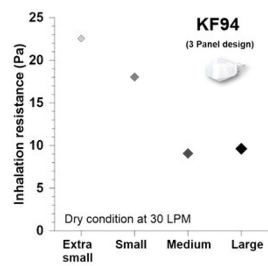
- IR tended to be higher with higher filtration efficiency, but several exceptions were found.
- IR at 90 LPM was greater than IR at 30 or 60 LPM, the differences were more remarkable for KF 94 (2P, 3P) and KF 99 than for the surgical mask, KFAD, and KF80.

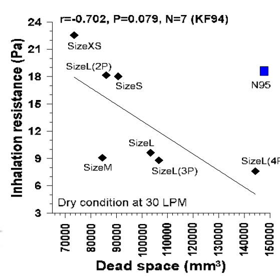




- IR was seldom affected by saturation 1 (600 g-water, 12%), whereas saturation 2 (2-min, 161%) or 3 (60-min, 222%) significantly increased IR. N95 and KF99 showed marked increases in IR by saturation 3.

2. Mask size and dead space





- An extra small mask had the highest IR followed by the small mask.
- The dead space had a negative relationship to IR (R = -0.702)

3. Regression models

	Model	B	beta	P	VIF	R^2	Corrected R^2
3	Constant	-44.31		0.002	1.03	0.42	0.38
	Filtration (Level)	11.32	0.55	0.000	1.22		
	Flow rate (LPM)	0.59	0.44	0.001	1.25		
	Moisture saturation (%)	0.07	0.24	0.069			
2	Constant	-30.55		0.014		0.37	0.34
	Filtration (Level)	10.50	0.51	0.000	1.00		
	Flow rate (LPM)	0.46	0.34	0.006	1.00		
1	Constant	-9.98		0.338		0.26	0.24
	Filtration (Level)	10.50	0.51	0.000	1.00		

Conclusions

- ✓ Filtration level had an inverse relationship to the inhalation resistance of face masks, but the explanatory power of this or any single factor was lower than anticipated and there were several exceptions according to design and wearing factors.
- ✓ Among various parameters related to IR, filtration and flow rate were the most powerful factors determining IR.
- ✓ In terms of design and wearing factors, greater dead space and dryness of the mask were most significant for reducing IR.
- ✓ In order to reduce the IR of a mask, minimizing that mask's moisture level, while increasing its dead space, is recommended.