Risks of N95 Face Mask Use in Subjects With COPD

Sun Young Kyung, Yujin Kim, Hyunjoong Hwang, Jeong-Woong Park, and Sung Hwan Jeong

BACKGROUND: The N95 filtering facepiece respirator (FFR) is the most popular individual protective device to reduce exposure to particulate matter. However, concerns have been raised with regard to its use because it can increase respiratory resistance and dead space. Therefore, this study assessed the safety of N95 use in patients with COPD and air-flow limitation. METHODS: This prospective study was performed at a tertiary hospital and enrolled 97 subjects with COPD. The subjects were monitored for symptoms and physiologic variables during a 10-min rest period and 6-min walking test while wearing an N95. RESULTS: Of the 97 subjects, 7 with COPD did not wear the N95 for the entire test duration. This mask-failure group showed higher British modified Medical Research Council dyspnea scale scores and lower FEV_1 percent of predicted values than did the successful mask use group. A modified Medical Research Council dyspnea scale score ≥ 3 (odds ratio 167, 95% CI 8.4 to >999.9; P = .008) or a FEV_1 < 30% predicted (odds ratio 163, 95% CI 7.4 to >999.9; P = .001) was associated with a risk of failure to wear the N95. Breathing frequency, blood oxygen saturation, and exhaled carbon dioxide levels also showed significant differences before and after N95 use. CONCLUSIONS: This study demonstrated that subjects with COPD who had modified Medical Research Council dyspnea scale scores ≥ 3 or FEV_1 < 30% predicted wear N95s only with care. *Key words: Air pollution; COPD; particulate matter; respirators; respiratory protective devices; safety.* [Respir Care 2020;65(5):658–664. © 2020 Daedalus Enterprises]

Introduction

Particulate matter (PM) consists of a complex mixture of solid and liquid organic and inorganic particles suspended in the air.[1] The most harmful particles are those with diameters ≤ 2.5 μm, which can penetrate and lodge deep inside the lungs.[1,2] Exposure to air pollutants, including PM, is associated with negative health impacts, and PM is considered one of the most important air pollutants associated with adverse health problems worldwide.[2,3] For example, many epidemiological studies have shown that PM has noxious effects in respiratory, cardiovascular, cerebrovascular, metabolic, and neuropsychiatric disorders as well as during pregnancy.[4-7] PM exposure is also associated with increased exacerbation in patients with COPD, asthma, and several other respiratory diseases, which thus results in increased hospitalization and mortality.[4,7-11] In addition, PM exposure increases the incidence of lung cancer and pneumonia.[12,13]

The best solution for reducing the health hazards associated with PM exposure is to remove the sources of PM via environmental interventions; however, this is very expensive and takes time. Therefore, individual interventions to protect against the adverse health effects of PM are required. The most popular practical solution to reduce individual exposure is the use of an N95 filtering facepiece respirator (N95 FFR), which is a respiratory protective device designed to achieve a very close facial fit and efficient filtration of airborne particles, blocking at least 95% of small particles (0.3 μm).[14] N95s are most commonly used by health-care and industrial workers to minimize exposure to microorganisms or airborne

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dust.[15-17] They are also frequently used in areas with high concentrations of air pollutants to protect against PM.[15,18,19] The use of face masks to decrease personal PM exposure has been shown to reduce systolic blood pressure in healthy volunteers during a 2-h walk.[15] Furthermore, N95 use during walking in areas with high atmospheric PM concentrations is associated with improvements in objective measures of myocardial ischemia, exercise-related increases in blood pressure, and heart rate variability in patients with coronary heart disease.[20]

However, the adverse physiologic impacts of N95 are a concern because N95 use can cause increased inspiratory and expiratory flow resistance and dead space.[14] The increased flow resistance can cause an increase in tidal volume, a decrease in breathing frequency, and a decrease in minute ventilation, with a concomitant decrease in alveolar ventilation.[14] In healthy subjects, wearing a gas mask increases breathing effort by ~1.5-fold.[21] In healthy health-care workers, N95 use did not cause any important physiologic burden during 1 h of use.[22] However, continuous use of the N95 that exceeded 4 h was associated with the development of headaches.[23] According to respiratory protection guidelines for the workplace, N95-induced increases in respiratory flow resistance, dead space, and physiologic load are small and generally well tolerated in healthy individuals and persons with impaired lung function.[14] Nevertheless, when the elderly or patients with respiratory disease, heart disease, or stroke wear an N95 to reduce PM exposure, they should consult their physician about the safety of N95 use.[24] The balance between the risks and benefits of N95 use in these patients, particularly patients with chronic pulmonary function impairment, is unclear. Therefore, we evaluated the safety and risk of N95 use in subjects with COPD, which is associated with chronic air-flow limitation and is substantially affected by PM exposure.

> **QUICK LOOK**
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> **Current knowledge**
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> Previous studies indicate that the use of the N95 face mask in patients with mild respiratory disease ($FEV_1 \geq 50\%$) did not induce significant adverse effects. However, the use of the N95 face mask could induce an increase in flow resistance and dead space.
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> **What this paper contributes to our knowledge**
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> In this prospective study, we evaluated the physiologic impacts of N95 face mask use in subjects with COPD and severe air-flow obstruction. Patients with COPD and with modified Medical Research Council dyspnea scale scores ≥ 3 or $FEV_1 < 30\%$ predicted should be careful when using N95 face masks because these may increase the risk of dyspnea and breathing discomfort.

Methods

Study Design and Subjects

A prospective panel study was performed between March and May 2015 at a tertiary hospital of Incheon, South Korea. In total, 97 patients were recruited from the Gachon University Gil Medical Center (Incheon, South Korea). All the subjects were diagnosed with COPD and were treated in the pulmonary division, with regular visits to the out-patient department. The inclusion criteria were age 19–80 y old, smoking history > 10 pack-years, and adequate physical activity to allow for hospital visitation via unassisted walking. The exclusion criteria were severe respiratory failure with long-term oxygen therapy; history of hospital admission within the previous 3 months due to COPD exacerbation; a history of invasive mechanical ventilation or noninvasive ventilation; severe renal or hepatic failure; history of heart failure; history of acute cardiovascular or cerebrovascular event within the previous 2 months; advanced stage of malignancy, with an expected survival within 6 months; or other severe pulmonary diseases (eg, tuberculosis-destroyed lung and severe bronchiectasis). Baseline data, including smoking history, the British modified Medical Research Council dyspnea scale (mMRC) questionnaire results, COPD Assessment Test (CAT) score, and spirometry and laboratory measurements were recorded in the case report forms.

All the subjects provided written informed consent, and the study was reviewed and approved by the institutional review board of Gachon University Gil Medical Center (GBIRB2015-300). The subjects were monitored for symptoms and safety during a 10-min rest period and 6-min walk test (6MWT) while wearing an N95 (3M 9210, 3M, St. Paul, Minnesota). We purchased the 3M 9210 face mask for this study; however, this device is no longer being manufactured (since 2014). Electrocardiogram and S_{pO_2} monitoring were continuous during the study. Systolic blood pressure, diastolic blood pressure, heart rate, breathing frequency, S_{pO_2}, and exhaled carbon dioxide (P_{ETCO_2}) were measured at baseline and during the 6MWT without a mask, 10 min rest with a mask, and 6MWT with a mask. If the subjects felt too uncomfortable to wear the N95 or their physiologic variables became unstable, they removed the mask immediately; these subjects were included in the mask failure group. Investigators (SYK, YJK, HJH) attended to these subjects and monitored them carefully until recovery.

Baseline Data Collection and Classification of COPD

The severity of COPD was evaluated by using the mMRC score, CAT score, and postbronchodilator FEV_1 percent of predicted according to the Global Initiative for Chronic Obstructive Lung Disease guidelines.[25] The mMRC dyspnea scale is a simple measure of breathlessness in COPD: grade 0, only experiences breathlessness on strenuous exercise; grade 1, experiences shortness of breath when hurrying on level ground or walking up a slight hill; grade 2, walks on level ground slower than people of the same age due to breathlessness or stops to catch breath when walking at a comfortable pace on level ground; grade 3, stops to catch breath after walking ~100 m or after a few minutes on level ground; and grade 4, too breathless to leave the house or breathless when dressing or undressing. The CAT is an 8-item unidimensional measure of health status impairment in patients with COPD. The score ranges from 0 to 40 and is closely correlated with the quality of life. The severity of air-flow obstruction in COPD was categorized by using postbronchodilator FEV_1 percent of predicted: $FEV_1 \geq 80\%$ predicted; FEV_1, 50–79% predicted; FEV_1, 30–49% predicted; and $FEV_1 < 30\%$ predicted.

Physiologic Variables and Symptom Questionnaire

Heart rate, breathing frequency, and S_{pO_2} were continuously monitored by using electrocardiogram monitoring and pulse oximetry during the study. Systolic blood pressure, diastolic blood pressure, and P_{ETCO_2} were measured at baseline and during the 6MWT without a mask, 10-min rest with a mask, and 6MWT with a mask. P_{ETCO_2} was measured by using capnography and was expressed as the mean (mm Hg) of 3 respirations. Symptoms associated with N95 use were evaluated by using a symptom questionnaire that included the presence of dyspnea, headache, dizziness, anxiety, facial pressure, and skin irritation.

Statistical Analyses

We used IBM SPSS Statistics for Windows/Macintosh, Version 23.0 (IBM, Armonk, New York) and SAS version 9.4 (SAS Institute, Cary, North Carolina) for statistical analyses. Categorical variables were compared by using the Fisher exact test, and continuous variables were compared by using the Mann–Whitney test, between the successful mask use group and mask failure group. To identify differences in the physiologic variables, repeated-measures analysis of variance was performed for blood pressure, heart rate, breathing frequency, S_{pO_2}, and P_{ETCO_2} by using the values from the baseline data without a mask as the covariant. The impacts of potential risk factors of the failure to wear a mask were analyzed by using univariate logistic regression analyses. Significant variables in the univariate analyses were included in the multivariate logistic regression analyses by using the Firth method to identify independent risk factors of N95 safety. The Firth method was used because one cell had a value of zero. Independent influences of risk factors of N95 safety were expressed as the odds ratio with 95% CI. Significance was considered as $P < .05$.

Results

Subject Characteristics

The mean ± SD age of the subjects was 68 ± 6.5 y and 94% were male subjects. The mean ± SD mMRC score was 1.5 ± 0.9 and the mean ± SD CAT score was 15.1 ± 8.2. The mean FEV_1 was 57.1% predicted and the most common air-flow obstruction category was moderate (FEV_1, 50–79% predicted; $n = 58$). Seven of the 97 subjects with COPD (7.2%) failed to wear the N95 during the test (Table 1). The mask failure group ($n = 7$) showed significantly higher mMRC scores and CAT scores as well as lower FEV_1/FVC, FEV_1, FVC, and S_{pO_2} values than did the successful mask use group ($n = 90$). The subjects who failed to wear the mask had an mMRC score ≥ 3 and $FEV_1 < 50\%$ predicted. The most common mask-associated symptom was dyspnea ($n = 8$); however, the subjects who failed to wear the mask had dizziness or headache as well as dyspnea.

Risk Factors for the Development of N95–Associated Complications

According to the multivariate logistic regression analyses, the independent risk factors for the failure to wear the mask included a high mMRC score, with an odds ratio of 12.58, 95% CI 1.49–105.95 ($P = .02$) (Table 2). In particular, an mMRC score of 3 was associated with a 167-fold increased risk of failure to wear the mask (95% CI 8.43 to >999.99; $P < .001$) (Table 3). In addition, $FEV_1 < 30\%$ predicted was associated with a 162.5-fold increased risk of failure to wear the mask (95% CI 7.36 to >999.99; $P = .001$).

Characteristics of the Mask Failure Group

Only one subject failed to wear the mask after 8 min during the rest period and showed increased P_{ETCO_2} and mask-associated symptoms, such as headache, dizziness, and facial pressure (Table 4). Most of the subjects ($n = 6$) in the mask failure group removed the mask during the 6MWT due to low S_{pO_2} or CO_2 retention. All the subjects exhibited decreased S_{pO_2}, increased P_{ETCO_2}, and dyspnea.

Table 1. Characteristics of the Subjects and Differences According to N95 Safety Outcome

Variable	All Subjects	Use of Mask		P
		Safe	Fail	
Subjects, n	97	90	7	
Age, mean ± SD y	68.0 ± 6.5	67.9 ± 6.4	68.6 ± 8.1	.81
Male, n (%)	91 (93.8)	85 (94.4)	6 (85.7)	.37
Current smoker, n (%)	26 (26.8)	25 (27.8)	1 (14.3)	.39
mMRC				
Score, mean ± SD	1.5 ± 0.9	1.4 ± 0.7	3.3 ± 0.5	<.001
Grade, n (%)				
0	6	6	0	
1	54	54	0	
2	23	23	0	
3	11	6	5 (45.5)	
4	3	1	2 (66.7)	
CAT score, mean ± SD	15.1 ± 8.2	14.3 ± 7.8	26.1 ± 3.7	<.001
Pulmonary function test				
FEV_1/FVC, mean ± SD	55.0 ± 13.1	56.3 ± 12.2	38.9 ± 13.5	.006
FVC, mean ± SD L	3.1 ± 0.7	3.2 ± 0.7	2.1 ± 0.7	.003
FVC % predicted, mean ± SD	73.5 ± 15.4	75.0 ± 14.6	54.6 ± 13.0	.002
FEV_1, mean ± SD L	1.7 ± 0.6	1.8 ± 0.6	0.8 ± 0.2	<.001
FEV_1 % predicted, mean ± SD	57.1 ± 18.9	59.3 ± 17.6	28.7 ± 9.2	<.001
FEV_1 % predicted, n				
≥80%	8	8	0	
50–79%	58	58	0	
30–49%	22	20	2	
<30%	9	4	5	
Physiologic variables, mean ±SD				
S_{pO_2}, %	96.4 ± 1.6	96.5 ± 1.5	94.9 ± 2.0	.02
P_{ETCO_2}, mm Hg	24.8 ± 6.8	24.4 ± 6.5	29.7 ± 8.6	.06
Mask-associated symptoms, n				
Dyspnea	8	2	6	
Dizziness/headache	3/1	0/0	3/1	
Facial pressure	5	4	1	

mMRC = modified Medical Research Council dyspnea scale
CAT = COPD Assessment Test
P_{ETCO_2} = end-tidal PCO_2

Table 2. Risk Factors for the Development of N95 Complications

Variable	Univariate Analysis			Multivariate Analysis		
	OR	95% CI	P	OR	95% CI	P
mMRC score	15.05	1.90–118.98	.01	12.58	1.49–105.95	.02
FEV_1% predicted	1.13	0.78–0.99	.03	1.09	0.83–1.00	.06

Risk factor analysis (Nagelkerke R^2 value = 0.732, Hosmer-Lemeshow goodness of fit with a χ^2 value = 0.779).
OR = odds ratio
mMRC = modified Medical Research Council dyspnea scale

Table 3. Risk of N95 Failure According to Binary Values of mMRC and FEV_1%

Variable	OR	95% CI	P
mMRC score ≥ 3	167.0	8.43–999.99	<.001
FEV_1% predicted < 30%	162.5	7.36–999.99	.001

Firth method was used for the logistic regression analysis because there was a cell with a value of zero.
mMRC = modified Medical Research Council dyspnea scale
OR = odds ratio

Physiologic Variables before and after Mask Use in the Successful Mask Use Group

In the mask-safe group, the breathing frequency, S_{pO_2}, and P_{ETCO_2} significantly differed before and after N95 use for 10 min in a resting state (Table 5). The heart rate, breathing frequency, and P_{ETCO_2} were significantly higher after the 6MWT with a mask than after the 6MWT without a mask. The S_{pO_2} levels were significantly lower after the 6MWT with a mask than after the 6MWT without a mask.

Table 4. Characteristics and Mask-Associated Symptoms in Subjects in the Mask Failure Group

Subject No.	Age, y/Sex	mMRC Score	FEV_1, % Predicted	Time of Recording	Respiratory Variables, Baseline/Final		Mask-Associated Symptoms
					Percentages	P_{ETCO_2}, mm Hg	
1	65/M	3	22	At rest with mask at 8 min	97/96	26/34	Headache, dizziness, facial pressure
2	76/M	3	26	During 6MWT without mask at 4 min	92/85	34/31	Dyspnea
3	69/F	3	35	During 6MWT without mask at 2 min, 43 s	96/83	26/42	Dyspnea, dizziness, anxiety
4	53/M	3	23	During 6MWT with mask at 5 min, 12 s	96/83	43/54	Dyspnea, dizziness, anxiety, cold sweating
5	78/M	3	48	During 6MWT with mask at 1 min 3 s	95/83	14/28	Dyspnea, dizziness, anxiety
6	75/M	4	28	During 6MWT with mask at 2 min 15 s	96/90	36/48	Dyspnea
7	65/M	4	19	During 6MWT without mask at 40 s	93/90	27/31	Dyspnea, anxiety

$n = 7$.
mMRC = modified Medical Research Council dyspnea scale
P_{ETCO_2} = end-tidal PCO_2
6MWT = 6-min-walk test

Table 5. Physiologic Variables after Use of N95 in Subjects Who Successfully Used a Mask

Parameter	Baseline without FFR	After 10-Min Rest with FFR	*P*	After 6MWT without FFR	After 6MWT with FFR	*P*
SBP, mm Hg	127.7 ± 15.0	129.6 ± 14.9	.30	133.8 ± 16.1	134.2 ± 16.5	.56
DBP, mm Hg	77.4 ± 11.1	80.1 ± 10.1	.003	79.4 ± 11.3	78.6 ± 11.5	.19
Heart rate, beats/min	77.6 ± 13.8	78.0 ± 14.0	.18	87.7 ± 17.0	92.4 ± 17.2	<.001
f, breaths/min	19.7 ± 1.2	20.7 ± 2.3	<.001	23.3 ± 2.6	25.7 ± 7.5	.002
S_{pO_2}, %	96.4 ± 1.6	96.0 ± 1.5	<.001	93.8 ± 2.6	93.0 ± 2.6	<.001
P_{ETCO_2}, mm Hg	24.8 ± 6.8	25.7 ± 7.3	<.001	34.0 ± 6.8	35.5 ± 7.6	<.001

$n = 90$.
Values are as mean ± standard deviation.
FFR = filtering facepiece respirator
6MWT = 6-min-walk test
SBP = systolic blood pressure
DBP = diastolic blood pressure
f = breathing frequency
P_{ETCO_2} = end-tidal PCO_2

Discussion

To our knowledge, this was the first study on the safety of N95 use in subjects with COPD and severely limited air flow. Patients with COPD are sensitive to PM, which can induce exacerbation of COPD, and experience respiratory failure, which can increase the risk of N95 use. The results of this study indicated that the subjects with COPD and with mMRC scores ≥ 3 or $FEV_1 < 30\%$ predicted should be careful to use N95s due to the increased risk for inducing hypoxic or hypercapnic respiratory failure.

The mean FEV_1 of the subjects enrolled in this study was 57.1% predicted, and 31 of the 97 subjects had an $FEV_1 < 50\%$ predicted. All the subjects were able to walk during regular out-patient clinic visits and showed stable baseline respiratory variables. The subjects were monitored continuously via electrocardiograms as well as for breathing frequency, S_{pO_2}, and subjective response by a respiratory physician (SYK, YJK, HJH) throughout the experiment. A number of studies examined the physiologic effects of face masks in subjects with mild respiratory disease (eg, asthma, COPD, and chronic rhinitis) while performing simulated work tasks.[26-29] For example, Harber et al[26] reported that subjects with mild COPD or asthma experienced adverse effects on ventilation while wearing half-mask respirators, which differ from N95s. In their study, the subjects with severe COPD and with an $FEV_1 < 50\%$ predicted were excluded.[27] They concluded that the respirator significantly affected several physiologic variables and subjective responses, and that the type of lung disease (eg, mild asthma or COPD) did not significantly affect the results.[27] In contrast, we enrolled and performed close monitoring of subjects with severe COPD, and these subjects showed significant adverse effects in terms of respiratory variables and subjective symptoms while resting or walking for 6 min and wearing an N95.

The adverse effects of N95 use in healthy people were originally studied in workers while the workers were wearing required respirators and showed elevated CO_2 levels and decreased O_2 levels during a qualitative respirator fit test.[30] In addition, the physiologic impact of the N95 has been studied in health-care workers.[22,23] Although the mask did not cause any adverse physiologic effects during 1 h of use, continuous use of the N95 for >4 h was associated with headaches and two subjects showed peak transcutaneous CO_2 levels > 50 mm Hg.[23] The effects of N95 use have also been assessed in pregnant women.[31-33] No differences were observed between pregnant and nonpregnant women in terms of physiologic variables (eg, heart rate, breathing frequency, O_2 saturation, or transcutaneous CO_2 level) after wearing an N95 for 1 h during sedentary activity or exercise.[31] However, exercising at 3 Metabolic Equivalent of Task while breathing through an N95 reduced the tidal volume, minute ventilation, and exhaled O_2 concentration but increased exhaled CO_2 concentration in pregnant women.[32] These results suggest that breathing through an N95 impedes gas exchange in pregnant women, and these factors should be considered when recommending N95 use.

According to the respiratory protection guideline of the American Thoracic Society,[14] FFRs generally induce minimum adverse physiologic effects and are tolerated by both healthy individuals and persons with impaired lung function. However, the American Thoracic Society agrees that FFR use can increase breathing resistance, dead space, and physiologic load. In particular, Lee and Wang[34] reported that N95 (model 8210; 3M) use yielded mean increments of 126% and 122% in inspiratory and expiratory flow resistance, respectively, measured by using rhinomanometry. Moreover, they reported that N95 use induced a mean 37% reduction in air-exchange volume.[34] According to the guideline for physicians of the Hong Kong Medical Association, the elderly, people with illness (eg, chronic lung disease, heart disease, or stroke), and pregnant women should consult their physician to determine whether they can use N95s because they may already have reduced lung volumes.[24]

In a study on the efficacy of N95s in subjects with coronary heart disease, the subjects walked for 2 h while wearing an N95.[20] All 96 subjects enrolled in that study tolerated the mask intervention well. Moreover, the mean ambulatory arterial blood pressure and heart rate were more stable in the subjects who used masks than in those who did not use a mask. Although patients with uncontrolled heart failure were excluded from that study, the results indicate that N95 use for <2 h is safe for people with coronary heart disease in a stable state.[20] Unlike that study, we found that subjects with COPD enrolled in this study showed significant differences in physiologic variables, depending on whether they used a mask. The subjects showed worsening of respiratory variables when they wore an N95, including increased breathing frequency, P_{ETCO_2}, and decreased S_{pO_2}. When considering the increase in respiratory resistance with N95 use, patients with COPD and low baseline pulmonary function may be considered to have a greater physiologic impact with mask use.

A major limitation of this study was that it was performed at a single center with a relatively small mask failure group. Nevertheless, the results are sufficient for informing guidelines on safe N95 use in patients with COPD. In the future, a larger population should be recruited from multiple institutes. Another limitation is that we used the 6MWT to evaluate the safety of N95 use during exercise. The 6MWT is simple and is often used to evaluate exercise tolerance. However, the safety of N95 use during 6 min of walking may not adequately reflect safety under real outdoor conditions; outdoor activities may last for varying durations of time and may involve varying levels of exertion. Most of the subjects in the mask failure group showed hypoxemia or hypercapnia and mask-associated symptoms during the 6MWT. Furthermore, other susceptible patients, such as those with asthma or severe heart failure, should be included in future studies of N95 use safety.

Conclusions

We generally recommend the use of N95s for patients with COPD for protection against PM exposure during outdoor activity under high PM conditions. However, patients with very severe COPD, mMRC scores $\geq$ 3, or FEV_1 < 30% predicted should be careful when using N95s. Performance of the 6MWT while wearing the N95 may predict mask-associated risks in patients with severe COPD. Also, patients should be warned to remove the N95s immediately on the onset of dyspnea, headache, or dizziness.

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