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호흡보호구에서 마스크커버가 밀착계수에 미치는 영향

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The Effects of Mask Covers on the Fit Factors of Respirators

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ABSTRACT

Objectives: 본 연구는 호흡보호구의 밀착도의 척도인 밀착계수 (FF)를 이용하여마스크에 마스크 커버를 씌웠을 때 호흡보호구의 밀착에 어떠한 영향을 미치는지 평가하고자 하였다.

Methods: 3개 회사의 호흡보호구 (1개 1/4형, 2개 반면형)를 선정하여25의 피검자 (남자 16, 여자 9)에게 마스크 커버를 씌우지 않은 마스크와 씌운 마스크를 착용하게 하고 정량적인 밀착도 검사 (QNFT)를 실시하여 밀착계수 (FF)를 측정하였다. 동일한 조건에서 각 피검자에게 3번의 QNFT를 실시였으므로 한 마스크 당 씌운 것 75회, 씌우지 않은 것 75회, 150회를 시행하여 비교하였고 3개 마스크에 총 450회를 시행하였다.

Results: 마스크 A (반면형)는 예상과는 다르게 마스크 커버가 있는 경우가 없는 경우보다 FF값이 더 높게 나왔으며 ($p<0.05$), 마스크 B (1/4형)와 마스크 C (반면형)은 마스크 커버가 없는 경우가 있는 경우보다 FF가 높게 나왔다. 마스크 B는 마스크 커버와 관계없이 FF가 너무 낮아 밀착에 문제가 있다고 판단되었으며 반대로 마스크 C는 마스크 커버에 영향을 받았으나 FF가 매우 높게 나와 밀착에는 큰 문제가 없다고 판단되었다.

Conclusions: 본 연구 결과는 마스크에 자신의 마스크 커버를 씌울 경우 밀착에 큰 영향은 없는 것으로 나타났으나 FF만 가지고 실험했기 때문에 제한적이며 실제 작업현장에서 밀착도에 영향을 주지 않는지를 결정하기 위해서는 작업장보호계수 (WPF)를 이용한 보다 많은 연구가 필요하다.

Key words : Fit factor, Mask cover, Quantitative fit test, Respirator

I. Introduction

If the facepiece of respiratory protection equipment (RPE) does not fit, it does not protect the wearer, regardless of how effectively other components of the equipment work. In other words, no RPE can provide optimum performance if there is leakage between facial skin and the facepiece, and one of the main sources of leakage is poor fit of the mask on the face. The fit of RPE on the wearer's face can be expressed as a fit factor (FF), and the face seal's protection level can be assessed by fit testing. Other considerations include the worker's willingness to wear RPE and the amount of time he/she wears it in the contaminated area. This is considered the wear factor, which is a measure of the percentage of time RPE is actually worn during work(Rajhans & Pathak, 2002). Even if a respirator has a high FF and it filters out contaminants effectively while being worn, overall protection is dramatically reduced if the respirator is not worn in the contaminated area even for brief periods. Therefore, a good fit and a high percent time of wearing a respirator are necessary for optimal respirator protection.

Some workers who should wear RPE do not wear

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the equipment consistently in contaminated areas. In a previous study(Chia, 1989), 75% driller and crusher attendants wore respirators all of the time, while only 50% of mechanics and drivers did. Reasons given for not wearing respirators all the time included ‘difficulties in communication’(53.6%), ‘feeling hot and sweaty’(53.6%), ‘wanting to smoke’(35.7%), and ‘breathing difficulty’(25%). Another study was reported that major reasons of not wearing respirators were ‘difficulty in breathing’(46.4%), ‘sweating’(38.75), ‘bothered by frequent removal’(20.8%), and so on(Kim et al., 1998). In a recent study, Han et al.(2009) reported that the main reasons for not wearing a respirator included ‘sweating’(27%), ‘thermal stress and humidity inside’(18%), ‘pain in the face or head’(15%), ‘difficulty in breathing’(15%), and so on(13%). For these reasons, many workers use a knit cover between the facial skin and facepiece of the respirator(Aiba et al., 1995). However, because using a knit cover while wearing a respirator may result in a poor facial seal, in general, industrial hygienists do not recommend the use of knit covers, even when mandatory. However, in reality, many workers use a knit cover despite warnings by the Korean Ministry of Employment and Labour that its use could compromise the facial seal. To reflect this point, several respirator manufacturers have produced and distributed knit covers(Mask cover hereafter) for use in Korea. At present, it is necessary to evaluate whether the use of mask covers influences the facial seal.

The objective of this research was to evaluate the effects of mask covers, designed for use on the company’s own half or quarter mask, on the FFs of 3 brands of respirators and to determine whether the use of mask covers is appropriate in the workplace.

II. Materials and Methods

1. Mask Covers

In Korea, 3 different types of mask covers are produced by 3 respirator manufacturers and are widely used here. Each mask cover only fits the facepiece of the respective company’s respirator. The 3 brands of respirators and their mask covers are shown in Figure 1.

Mask cover A. As this product is made of synthetic pulp, which is the raw material used in diapers, it absorbs water very well and prevents allergy. Because it is relatively thick, no mark is left on the user’s face by the respirator facepieceon after wearing the respirator for an extended period. This cover was first developed in Korea, and it is widely used for the company’s half mask respirator(Figure 1a).

Mask cover B. Cotton is the primary material for this product. This fabric absorbssweat well and is relatively thick, just like mask cover A(Figure 1b). This fabric has excellent elasticity due to its elastic rubber bands. Its surface is shoddy and has a towel-like coarseness. It is used for the quarter mask respirator manufactured by its supplier.

Mask cover C. This product is composed of nonwoven fabric having excellent elasticity. Because it is very thin and its surface is dense, it is likely that this product does not absorb sweat well(Figure 1c). However, this product is useful for preventing allergic

a. Mask cover A　　b. Mask cover B　　c. Mask cover C

Figure 1. Mask covers and their respirators

reaction and marks on the face caused by the respirator. It is made to cover the half mask respirator produced by its manufacturer.

2. Fit test subjects and quantitative fit testing (QNFT) procedures

Student volunteers from Inje University in Korea were asked to participate in the study. The study subjects included 16 men and 9 women. The age range of the subjects was 22-27 years. Each subject underwent a physical examination and pulmonary function test at the Health Research Centre of Inje University. No subject had a facial deformity or a moustache/beard.

For each subject, each respirator without a mask cover was first fit-tested 3 times, and then the same respirator covered with mask covers was fit-tested in an identical manner 3 times. Accordingly, each respirator was tested 75 times without a mask cover(25 subjects ×3 times per subject = 75) and 75 times for the respirator with mask cover for a total number of 150 fit tests, resulting in 450 fit tests for all 3 respirators.

The filter of each respirator was replaced for each company's 'special-grade filter' certified by Korean standards for particulate respirators, the same as the P3 filter of BS EN 143(BSH, 2000), the filter of which(at an air flow of 95 L/min) captured at least 99.95% of airborne particles. The in-mask sampling probe(TSI fit test probe) was placed at the same level of the inside surface of the facepiece by using a TSI probe-inserting tool. The instrument used for fit testing was a Portacount 8038TM(TSI Inc., St. Paul, MN, USA) connected to an IBM portable personal computer.

Each respirator was quantitatively fit-tested by each subject according to the protocol written in the OSHA regulations(OSHA, 2002). Before fit testing, fit checks were conducted to determine whether the respirator was properly adjusted to the face of the subject. If a subject felt leakage between the skin of the face and the mask facepiece, he/she wore the respirator again, and the fit check was repeated. During the fit test, the subjects were asked to perform 6 fit test exercises: (1) normal breathing, (2) deep breathing, (3) movement of the head from side to side and up and down, (4) reading or talking, (5) jogging, and (6) normal breathing. Each exercise was performed for 90 s. All test respirators were disinfected after each use. The FF was determined as the overall value.

3. Data analysis

The goodness-of-fit test was conducted using the LogNorm2® statistical package(InTech Software Corp., Tulsa, OK, USA). Natural logarithm-transformed fit factors(ln-FFs) were assessed before statistical analysis was conducted, and then they were used for all subsequent analysis. A two-tailed paired Student's t-test was conducted to determine if the mean of the ln-FFs for respirators with mask covering were different from those without mask covering. Wilcoxon's test was also performed to determine whether there were significant differences in the paired raw FF values(not ln-FFs) for respirators with and without mask covers. Statistical tests were conducted using the SPSS statistical package, and each P-value was reported.

III. Results

The results of the Shapiro-Wilk W test performed using the LogNorm2® statistical package indicated that the FFs were not normally distributed; however, a log-transformation of the data resulted in an approximately normal distribution. Accordingly, statistical analyses for paired Student's t-test were conducted using the ln-FFs.

Table 1 shows each subject's geometric mean of fit factors(GMFFs) measured in 3 time trials for each respirator brand with and without mask covers. Respirator A without mask covering had a GMFF of 70.3 for all subjects and a geometric standard deviation(GSD) of 1.886, compared with a GMFF of 76.9 and a GSD of 1.567 with the mask cover($p < 0.05$). Contrary to expectations, the FFs for respirator A were generally greater with the mask cover. In other words, the respirator exhibited a better fit with a mask cover. For respirator B, the GMFF and GSD for all subjects with mask covering was 20.4 and 1.381, respectively, compared with 18.2

Table 1. Geometric means* of the FFs for 3 respirators with and without mask covering

Subjects (Male/Female)	Respirator A		Respirator B		Respirator C	
	Without	With	Without	With	Without	With
A (M)	71.3	88.8	15.3	15.3	2793.8	8698.0
B (M)	63.5	82.5	13.2	13.1	11023.0	6190.1
C (M)	72.7	72.0	18.3	15.3	1930.7	3498.2
D (M)	54.0	57.9	13.6	13.5	4300.4	3394.7
E (M)	85.3	82.2	15.0	17.3	27215.0	8342.7
F (M)	28.1	27.7	14.7	14.7	13586.8	750.4
G (M)	58.5	58.7	17.6	17.6	1400.3	614.0
H (M)	46.0	53.9	18.3	15.3	4179.5	7563.1
I (M)	56.4	59.2	14.3	15.0	13796.0	2392.4
J (F)	117.4	103.3	26.3	22.0	15150.8	19775.5
K (F)	156.2	144.6	36.3	41.0	9902.3	8013.8
L (M)	74.7	71.8	22.9	22.3	4860.0	2143.4
M (F)	69.4	88.7	25.6	21.6	6230.2	873.3
N (F)	113.6	125.6	18.3	21.6	7812.7	156.2
O (M)	10.3	33.9	9.3	6.2	16633.4	7936.4
P (F)	81.0	81.2	22.9	44.9	463.6	21.5
Q (M)	54.9	97.7	19.9	10.3	12439.0	2960.3
R (F)	90.9	91.0	18.6	10.3	15134.8	6730.0
S (M)	137.2	155.0	15.5	13.1	3398.0	4527.4
T (F)	91.3	80.6	23.6	6.0	9113.4	5704.0
U (M)	69.5	72.5	24.6	31.9	904.7	501.9
V (M)	48.6	57.3	38.1	9.9	3602.7	2974.0
W (F)	54.0	67.4	28.7	22.8	6255.0	5123.0
X (F)	39.2	42.8	20.0	15.3	457.8	463.9
All GM	70.3	76.9	20.4	18.2	7706.0	4376.3
GSD	1.886	1.567	1.381	1.620	4.114	5.371
p-value	0.016		0.057		0.004	

* Each subject's FF is the geometric mean calculated for 3 fit testing trials.

and 1.620 without mask covering, respectively there(p = 0.057 for GMFF). Respirator B exhibited the lowest FF among the 3 respirators, regardless of mask covering. Respirator C, the half mask, had a very high FF in the absence of mask covering(GMFF = 7706.0; GSD = 4.114). With a mask cover, this respirator had much lower GMFF and GSD values of 4376.3 and 5.371, respectively, although all subjects-excluding subject P (F)-had very high GMFFs. The difference between the 2 groups was significant(p< 0.01 for GMFF). For respirator C, the FF was clearly reduced when a mask cover was used.

Wilcoxon's test was conducted using all of the raw FF values in the paired test, and the findings are shown in Table 2. The result of this statistical analysis was virtually identical to the aforementioned results. For respirator A, 46 of the 75 paired fit testing trials (61.3%) had higher FFs with mask covering than without mask covering, and the FF values were significantly different between the 2 groups(P < 0.05). In contrast, the FFs for respirator B were higher without mask covering than with mask covering for 54.7%(41/75) of the paired trials, and 14.7%(11/75) of the trials had the same values between the 2 groups. The dif-

Table 2. Difference inthe FF for the 3 respirators between the with mask covering and without mask covering conditions

Respirator	FF without mask cover − FF with mask cover		Number (s) of nodifference	Total numbers of paired FFs	P-value
	Numbers of positive	Numbers of negative			
A	29 (38.7%)	46 (61.3%)	0	75	0.008
B	41 (54.7%)	23 (30.7%)	11	75	0.016
C	54 (72.0%)	21 (28.0%)	0	75	<0.001

ference in FFs between the 2 groups was significant ($p < 0.05$). No significant differences were observed in the FFs between the 2 groups for respirator B, probably due to the very low FFs. For respirator C, higher FFs were observed in the without mask cover group for 72%(54/75) of the trials($p < 0.01$). It was thought that the very low P-value was caused by the high FFs in all cases. The OSHA criterion was satisfied(overall FF of 100 for the half mask) for respirator C in all fit testing trials, except for subject P with mask covering, regardless of the use of a mask cover(unlike in the USA and UK, there is no fit testing regulation for respirators in Korea).

IV. Discussion

Proper fit is a very important factor to consider when selecting a respirator. Wearing a poorly fitting respirator may be more dangerous than not wearing a respirator at all. Workers may believe they are protected, but when entering a hazardous environment, they will be exposed to hazardous substances contrary to their thinking. Fit testing has therefore been a requirement in the US for more than 40 years, in order to ensure adequate fitting for respirators since the introduction of in the American Standard ANSI Z88.2 in 1969 (ANSI, 1969). Recently, several laws in the UK stipulated that tight-fitting RPE must be fit-tested as part of the selection process(HSE, 2010; HSE, 2011). However, as many countries, including Korea, still have no regulations for fit testing for individuals, many difficulties exist in selecting an adequate fit respirator. Even though Korea has no fit test regulations, many Korean industrial hygienists strongly recommend fit testing for people working in very hazardous environments, such as workers performing asbestos removal.

The FF, a measure of the sealing of a respirator to the face of the wearer as determined by QNFT, is not measured when respirators are used in the workplace(Myers et al., 1984, Wallis et al., 1993). Nevertheless, the FF is one of the most fundamental and important parameters describing the fit performance of respirators; it provides some indication, albeit incomplete, of the expected performance of the respirator on the wearer in the workplace(Brown, 1992; Rajhans&Pathak, 2002). In the USA, minimum FFs of 500 for a tight-fitting full face mask and 100 for a half mask have been set(OSHA, 2002), whereas FFs of 2000 for a full face mask and 100 for a half mask have been recommended in the UK(HSE, 2011). The important difference is that in the UK, HSE requires that a satisfactory score for each of the fit test exercises, whereas in the USA, only the overall figure is used.

Without mask covering, respirators A(half mask) and B(quarter mask) had very low GMFFs of 70.3 and 20.4, respectively. Compared with the minimum FF of 100 in the USA/UK, these respirators do not generally achieve the required level of protection. In other words, these two respirators had unacceptable level of fit, compared with the regulation of USA/UK.Meanwhile, respirator C(half mask) without mask covering had a very high GMFF of 7706.0, and it provided adequate protection to all subjects. Accordingly, respirator C had an excellent fit performance.

When respirators were covered with mask covers, the GMFFs of respirator A were generally higher than those without mask covering($p < 0.05$). Thus far, it has been assumed that mask covering could result in an inadequate fit, and consequently, many industrial hygienists and governmental authorities have recommended refraining from using mask or knit covering(Aiba et al., 1995). However, the FF clearly increased in most tests when respirator A was covered by the mask cover. The reason for this result may be interpreted in two different ways. First of all, the mask cover for respirator A may be actually effective to increase protection performance. Secondly, the respirator A was poorly designed, having unacceptable GMFF level of 70.3 by the USA/UK regulation; this defect was covered by mask cover. In this case mask cover may not provide fit performance actually, but make up for the poor design. Anyway it is very difficult to say that this mask covering provides respirator A with a good fit because this result was still not verified in the actual workplaces as workplace protection factor(WPF).

For respirator B, there were no significant differences in the GMFFs between the both mask cover conditions for each subject(Table 1, paired Student's t-test, p = 0.057), but the difference in the paired FFs was significant(Table 2, Wilcoxon's test, p = 0.016). Because respirator B displayed very low FFs in most of the measurements, it was likely that mask covering had no effect on the fit performance. Therefore, respirator B may not guarantee an adequate fit, irrespective of mask covering. Considerable caution must be taken to select the best respirator in very hazardous environments.

In contrast, the FFs for respirator C without mask covering were very high. The GMFF calculated for the 3 FFs for all subjects was 7706.0(range, 457.8-27251.0, Table 1). With mask covering, this respirator displayed a GMFF of 4376.3(range, 21.5-19775.5, Table 1, p = 0.004; Table 2, p< 0.001), which was much lower than that without mask covering. However, the FFs of all subjects, except subject P, were very high compared with the pass level of 100 in the USA. This finding implied that respirator C would provide a very good fit for most subjects, even though mask covering decreased its fit performance. In other words, irrespective of mask covering, respirator C had an outstanding fit performance for most subjects. However, because a noticeably low GMFF of 21.5 was observed for subject P in mask covering condition, special caution is required(for example, fit testing) when wearing the respirator with a mask cover.

There was no such study on mask covering has been performed, with which we can compare our results. A similar study was conducted to determine the effects of strapped spectacles on the FFsobtained during quantitative fit testing(Spear et al., 1999); however, those findings cannot be directly compared with the present study. However, to our knowledge, this is the first study of its kind to evaluate how mask covering affects the fit performance of respirators.

V. Conclusion

Respirator A had higher FFs with mask covering than without mask covering; however, it was very difficult to conclude that mask covering could actually provide respirator A with good fit performance. In contrast, reduced FFs were observed when respirators B and C were covered with mask covers. Because very low FFs were obtained with respirator B, regardless of mask covering, mask covering had little effect on its fit performance. Unlike respirator B, respirator C had very high FFs, irrespective of mask covering, and the fit performance for this respirator was significantly decreased by mask covering. The resultsdemonstrated that the prevailing thinking that mask covering results in a poor fit may not be applicable in all cases, if mask coverusesonly on the company's own respirator. But further researches should be necessary to confirm these findings to the actual working conditions using WPF.

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