Fit Abilities and Usability of Standard and Alternative Respirators for Small Face Health Workers in Thailand

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Abstract

Objective: To evaluate the fit abilities and usability of a NIOSH-approved N95, certified KN95, and KF94 respirators with a hook among Thai health workers who typically have small faces.

Methods: A descriptive study was conducted involving 47 Thai health workers with small facial dimensions, as defined by the NIOSH Bivariate Panel. The study assessed the fit abilities and usability of both standard and alternative respirators, including the NIOSH-approved N95 respirator, as well as the KN95 and KF94 respirators, which are certified.

Results: The mean $\pm$ standard deviation fit factor values for each type of respirator were as follows: N95 = 125.9 ± 60.8, KN95 = 18.9 ± 8.53, and KF94 = 27.9 ± 22.7. In the fit criteria assessment, 61.7% of participants rated the N95 as providing a well-fitted feeling, compared to 14.9% for the KN95 and 12.8% for the KF94. In terms of comfortability, 42.6% of participants rated the N95 as the most comfortable, followed by 29.8% for KF94 and 25.6% for KN95. For breathability, 83.0% rated KF94 as the most breathable, followed by 72.3% for KN95 and 63.8% for N95.

Conclusions: Only the N95 respirator passed the fit test and demonstrated appropriate fit abilities, including the highest rate of perceived well-fit feeling. In terms of usability, the N95 was rated as the most comfortable, while the KF94 was identified as the most breathable.

Keywords: N95; KN95; KF94; fit abilities; usability

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ความกระชับและความสามารถในการใช้งานของอุปกรณ์คุ้มครองความปลอดภัยระบบทางเดินหายใจมาตรฐานและทางเลือกในบุคลากรสุขภาพใบหน้าขนาดเล็กในประเทศไทย

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บทคัดย่อ

วัตถุประสงค์: เพื่อประเมินความสามารถในการกระชับพอดี (fit abilities) และความสามารถในการใช้งาน (usability) ของอุปกรณ์คุ้มครองความปลอดภัยระบบทางเดินหายใจ ในบุคลากรสุขภาพไทยที่มีใบหน้าขนาดเล็ก เพื่อให้เกิดความมั่นใจในการป้องกันระบบทางเดินหายใจอย่างมีประสิทธิภาพ

วิธีการศึกษา: การศึกษาแบบพรรณนา อาสาสมัครทั้งหมด 47 คน ที่มีใบหน้าขนาดเล็กตาม NIOSH Bivariate Panel การทดสอบความกระชับและความสามารถในการใช้งานของอุปกรณ์คุ้มครองความปลอดภัยระบบทางเดินหายใจมาตรฐานและทางเลือก ได้แก่ หน้ากาก N95 ซึ่งผ่านการรับรองมาตรฐานจากสถาบันความปลอดภัยและอนามัยในการทำงานแห่งชาติ ประเทศสหรัฐอเมริกา (NIOSH) หน้ากาก KN95 และ KF94 ที่ผ่านการรับรองตามมาตรฐาน GB19083-2010 และ MFDS KF94 ตามลำดับ และใช้งานร่วมกับตะขอหรือคลิปเกี่ยวสายรัดของหน้ากาก โดยใช้เครื่องวัด Quantitative Fit Testing เพื่อทดสอบความกระชับของอุปกรณ์คุ้มครองความปลอดภัยระบบทางเดินหายใจในขณะที่อยู่ในอิริยาบถต่าง ๆ ซึ่งเป็นไปตามเงื่อนไขของ OSHA Compliant Fit Testing Protocol การประเมินความสามารถในการใช้งานโดยใช้แบบสอบถาม เป็นคำถามเกี่ยวกับ ระดับความกระชับ ระดับความความสบาย และความสะดวกในการหายใจขณะสวมอุปกรณ์คุ้มครองความปลอดภัยระบบทางเดินหายใจแต่ละแบบ

ผลการศึกษา: ค่าเฉลี่ยและส่วนเบี่ยงเบนมาตรฐานของค่าความพอดีในอุปกรณ์คุ้มครองความปลอดภัยระบบทางเดินหายใจ ได้แก่ N95 125.9 ± 60.8, KN95 18.9 ± 8.53 และ KF94 27.9 ± 22.7 171 การประเมินความกระชับ ได้แก่ N95 ร้อยละ 61.7, KN95 ร้อยละ 14.9 และ KF94 ร้อยละ 12.8 การประเมินความความสบาย ได้แก่ N95 ร้อยละ 42.6, KN95 ร้อยละ 25.6 และ KF94 ร้อยละ 29.8 การประเมินความสะดวกในการหายใจขณะสวมใส่ ได้แก่ N95 ร้อยละ 63.8, KN95 ร้อยละ 72.3 และ KF94 ร้อยละ 83.0

สรุป: หน้ากาก N95 เท่านั้นที่ผ่านการทดสอบ fit test มีอัตราระดับความการชับที่เหมาะสมและอัตราระดับความสบายในการสวมใส่สูงที่สุด ขณะที่หน้ากาก KF94 มีอัตราความสะดวกในการหายใจขณะสวมใส่มากที่สุด

คำสำคัญ : อุปกรณ์คุ้มครองความปลอดภัยระบบทางเดินหายใจมาตรฐาน; อุปกรณ์คุ้มครองความปลอดภัยระบบทางเดินหายใจทางเลือก; ความกระชับ; ความสามารถในการใช้งาน

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Background

Certified KN95 and KF94 respirators were recommended PPE for caring for suspected or confirmed COVID-19 patients during non-aerosol-generating procedures (non-AGPs) by the Chinese Center for Disease Control and Prevention (Chinese CDC) and the Korea Centers for Disease Control and Prevention (KCDC) [1-2]. Certified KN95s and KF94s provided effective, cost-saving, and more available alternatives to N95s[3-5]. The Centre for Disease Prevention and Control (CDC) guidance highlighted the importance of proper donning, annual fit testing (in accordance with Occupational Safety and Health Administration standards, OSHA), and respirator selection based on facial size[6]. The National Institute for Occupational Safety and Health (NIOSH) defined facial panels (small, medium, and large) based on width and length measures[7]. Thai facial anthropometry showed a predominance of small face types[8-9]. Few studies examined alternative respirators in Thai health workers[10]. While KN95s with hooks or sponge nosepieces showed no difference from N95s, KF94s with hooks significantly improved fit among small-face groups. The Hook Mask improved the fit of the respirator and provided a more secure seal around the face[10]. To date, research on fit ability and usability of certified alternative respirators in Thai health workers remains scarce.

Study design and setting

A descriptive study was conducted in September 2024 to evaluate the fit abilities and usability characteristics of standard respirators and alternative hook-style respirators among small-faced Thai health workers at Srinagarind hospital, Faculty of medicine, Khon Kean University, Thailand.

Methods

Thai health workers at Srinagarind Hospital served as the study population.

Inclusion criteria: Participants were aged 18–60 years, classified as small face size by the NIOSH Bivariate Panel, had no facial anomalies or hair between the skin and sealing surface, and had blood pressure within 90/60–140/90 mmHg.

Small face size was 1-3 cell NIOSH Bivariate panel, including face width and face length measurement in millimeters. In detail, the face width (Bizygomatic breadth) is a maximum horizontal distance from the left to the right zygomatic arch and the face length (Mento-nasal length) is a midsagittal plane from the menton to the sellion landmark.

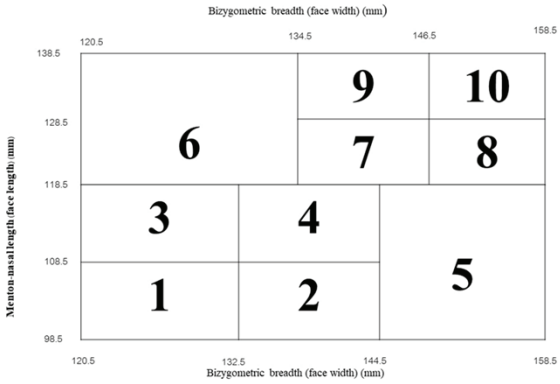


Figure 1 NIOSH Bivariate Panel

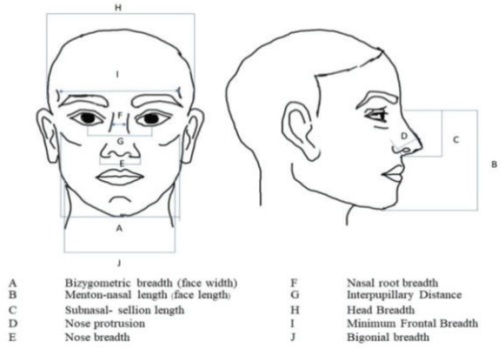


Figure 2 Facial Anthropometric measurement

Exclusion criteria: Participants were excluded if they had a history of heart or lung disease, hypertension, recent respiratory infection, pregnancy, anxiety, hyperventilation, claustrophobia, dizziness, vertigo, seizure disorders, or latex allergy. Those who smoked within 30 minutes before the fit test were also excluded.

Sample size calculation

The sample size was calculated by the Infinite population mean formula, Winpepi program. Using assumed S.D. = 68.77 from the N95 fit factors of a previous study[11]. The confidence interval was 95%, and the acceptable difference was 20.25. Lastly, the calculated maximum sample size was 47 participants.

Research tools

1. NIOSH-Approved N95 Respirator

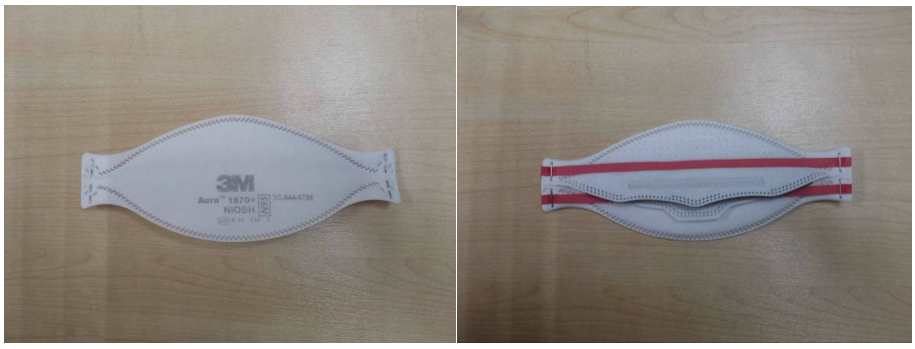


Figure 3 NIOSH-Approved N95 Respirator

The respirator provided a minimum filtration efficiency of 95% for non-oily particles ≥0.3 μm. There is a three-panel flat-fold design with an adjustable cushioned nose clip and dual elastic headbands to ensure a secure fit. The respirator consisted of three polypropylene layers (spunbond outer, melt-blown filter, and non-woven inner) and complied with ASTM F1862 Level 3 standards, offering high fluid resistance for clinical use.

2. Certified KN95 Respirator (China GB19083-2010 standard)

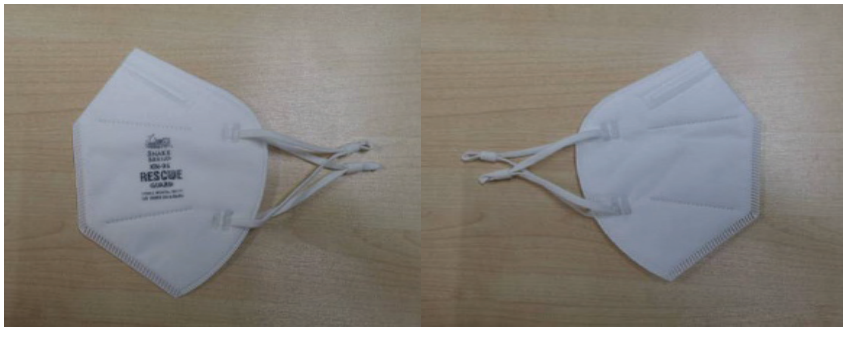


Figure 4 Certified KN95 Respirator (China GB19083-2010 standard)

The respirator provided >95% filtration efficiency for 0.3 μm particles. There is a 3D foldable design with an adjustable nose clip and elastic ear loops. The four-layer structure comprised non-woven polypropylene, electrostatic filter cotton, melt-blown polypropylene, and a soft inner non-woven layer.

3. Certified KF94 Respirator (MFDS KF94 standard)

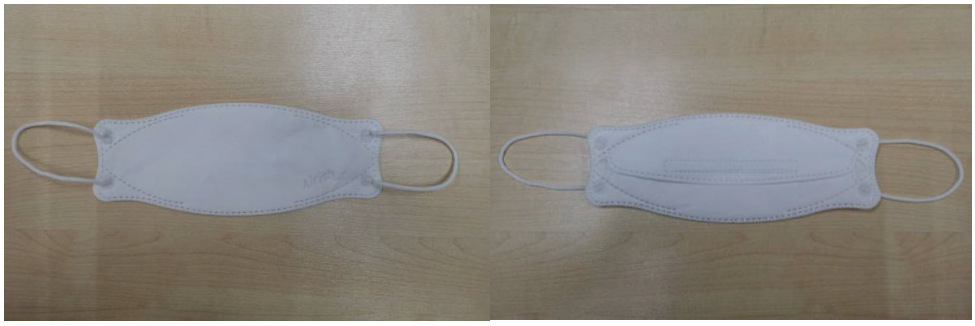


Figure 5 Certified KF94 Respirator (MFDS KF94 standard)

The respirator provided ≥94% filtration efficiency for ≥0.4 μm particles. It featured a folding design with an adjustable nose clip, elastic ear loops, and fluid resistance. The four-layer structure comprised outer and inner spunbond polypropylene, a support layer, and a melt-blown filter.

4. OSHA Respirator Medical Evaluation Questionnaire Part A: to determine the health worker's ability to use a respirator before the fit testing or respirator utilization.

5. Blood pressure monitor

6. Digital facial caliper

7. Quantitative fit testing machine (Model: Porta Count 8048 from TSI, serial number 8048181406, calibrated with Porta Count Bench Two system)

8. Fit criteria and Usability assessment questionnaire

9. Hook mask



Figure 5 Hook mask

Data collection

A total of 47 participants with normal blood pressure and small face sizes were recruited. Each participant scheduled an appointment for testing and provided informed consent after a detailed explanation of the study was provided. Upon arrival, participants rested for 30 minutes and secured their hair, after which they completed the OSHA Respirator Medical Evaluation Questionnaire. Participants were provided with instructions regarding the study procedures and the proper donning and doffing of respirators in accordance with NIOSH recommendations. Before donning, participants washed and dried their hands and inspected the respirator for any signs of damage, contamination, or moisture. The respirator was then donned correctly by positioning it beneath the chin, securing the head straps or ear loops, and molding the nosepiece to ensure an appropriate fit. A user seal check was subsequently performed to verify an adequate facial seal. Following respirator removal, participants washed their hands thoroughly with soap and water or, when unavailable, used a hand sanitizer containing at least 60% alcohol. Participants wore each assigned respirator for at least 5 minutes before testing, and all equipment was prepared accordingly. A user seal check was performed, followed by a quantitative fit test, and the test results were recorded. The following actions were performed based on the Modified Ambient Aerosol CNC Quantitative Fit Testing Protocol for Filtering Facepiece Respirators[6]. The protocol included the following exercises: bending over (50 seconds), talking (30 seconds), head side-to-side (30 seconds), and head up-and-down (39 seconds). Afterward, participants rested for 15 minutes and completed the Fit Criteria and Usability Assessment Questionnaire while equipment preparation continued. These procedures were consistently applied for each respirator type using a similar sequence of steps. Respirator fit testing was conducted sequentially on N95, KN95, and KF94 respirators. The primary outcome of the study was the fit factors, whereas the secondary outcomes included fit criteria, comfortability, and breathability. The Fit factor is calculated with the formula

$$\text{Fit factor} = C_{out} / C_{in}$$

C_{out} = the concentration of particles outside the mask (ambient concentration)

C_{in} = the concentration of particles inside the mask and is also presented.

The fit factor passed level was at least 100. Determining an overall fit factor from individual exercise fit factors entails converting the exercise fit factors to penetration values, computing the average, and converting the outcome back to the fit factor, as delineated by the provided equation.

Overall fit factor = $N/(1/FF_1+1/FF_2+1/FF_n)$

N = The number of exercises,

FF_1 = The fit factor for the first exercise,

FF_2 = The fit factor for the second exercise,

FF_n = The fit factor for the nth exercise.

There were three parts to the fit criteria and usability assessment. For instance, fit criteria, comfortability by comfort criteria, and breathability refer to the OSHA Fit testing procedure[6]. Rating 1-5 in each aspect was the measurement result, equal to or more than 4 scores was acceptable. Moreover, the score $\geq$ 4 in all aspects of the Fit criteria, comfort criteria, and breathability indicated that the respirator was perceived as well-fit feeling, comfortable, and breathable by turn. Appropriate fit abilities referred to passing the fit test and a well-fit feeling.

Fit Criteria and Scoring System:

Respirator fit was evaluated using seven criteria: proper positioning of the chin, appropriate strap tension, fit across the nasal bridge, adequate coverage from nose to chin, stability during wear, correct positioning as assessed by mirror inspection, and self-observation of overall fit. Each criterion was rated using a 5-point Likert scale, where 1 = very poor, 2 = poor, 3 = indifferent, 4 = good, and 5 = excellent. Comfort Criteria and Scoring System: Respirator comfort was assessed based on four criteria: alignment of the mask on the nose, adequate space for eye protection, sufficient space for verbal communication, and the position of the mask on the face and cheeks. Each criterion was rated using a 5-point Likert scale, where 1 = very uncomfortable, 2 = uncomfortable, 3 = indifferent, 4 = comfortable, and 5 = very comfortable. Breathability Assessment: Participants rated the ease of breathing while wearing the respirator using a 5-point Likert scale, where 1 = very difficult to breathe, 2 = difficult to breathe, 3 = indifferent, 4 = easy to breathe, and 5 = very easy to breathe.

Data recording and Data analysis

The results were recorded in the data record form and then imported into the Microsoft Office Excel 2010 program using double data entry. Subsequently, data analysis was performed using SPSS version 28 (IBM SPSS Statistics for Macintosh, Version 28.0. Armonk, NY: IBM Corp).

Ethical approval

The study was conducted following the Declaration of Helsinki and was approved by the Institutional Review Board (or Ethics Committee) of the Center for Ethics in Human Research at Khon Kaen University (HE671398) on 26 July 2024. The personally identifiable information was concealed.

Results

The majority of participants were female (70.2%), medical students (63.8%), and classified as Cell 1 of the NIOSH Bivariate Panel (70.2%) (Table 1)

Table 1 Demographic data

Variables	Values (N=47)
Sex	
Male	14 (29.8%)
Female	33 (70.2%)
Occupation	
Physician	9 (19.2%)
Nurse	6 (12.8%)
Nursing Assistant	3 (6.38%)
Medical student	27 (57.5%)
Safety officer	2 (4.27%)
NIOSH Bivariate panel	
Cell 1	33 (70.2%)
Cell 2	3 (6.38%)
Cell 3	11 (23.4%)
Previous respiratory PPE used	
N95	32 (68.0%)
KN95	8 (17.0%)
KF94	11 (23.4%)
Disposable medical face mask	47 (100.0%)
Age (year)	Mean $\pm$ S.D.
	25.2 $\pm$ 4.63
Face dimension (mm)	Mean $\pm$ S.D.
Width	123.2 $\pm$ 7.28
Length	107.6 $\pm$ 12.4

The N95 respirator demonstrated the highest mean fit factor (125.9 ± 60.8; 95% CI: 108.0–143.7) and the highest fit test pass rate (57.4%). Across all demographic groups, the highest fit factor values were consistently observed with the N95 respirator. Mean fit factors for the N95 were 167.2 ± 51.1 (95% CI: 137.6–196.7) among males (29.8%), 135.4 ± 61.1 (95% CI: 111.7–159.1) among medical students (63.8%), and 124.1 ± 62.3 (95% CI: 102.0–146.2) among participants in Cell 1 (70.2%) (Table 2).

Table 2 Fit factors

Variables (N=47)	Fit factor of respirators					
	N95		KN95		KF94	
	Mean ± S.D.	95% CI	Mean ± S.D.	95% CI	Mean ± S.D.	95% CI
Fit factors	125.9 ± 60.8	(108.0,143.7)	18.9 ± 8.53	(16.4,21.4)	27.9 ± 22.7	(14.5,30.9)
Passing rate of fit test (%)	27 (57.4%)		0 (0%)		1 (2.12%)	
Sex						
Male n=14	167.17 ± 51.1	(137.6,196.7)	18.3 ± 6.43	(14.6,22.0)	21.1 ± 8.54	(16.2,26.1)
Female n=33	108.7 ± 56.6	(88.3,128.4)	19.5 ± 9.36	(15.8,22.5)	23.4 ± 33.0	(11.7,35.1)
Occupation						
Physician n=9	127 ± 68.5	(81.6,173.7)	16.9 ± 5.24	(13.4,20.4)	16.7 ± 4.15	(13.9,19.5)
Nurse n=6	91.7 ± 51.3	(35.8,200.00)	13.7 ± 3.22	(5.68,21.7)	13.3 ± 0.58	(11.9,14.8)
Nursing Assistant n=3	109.9 ± 23.5	(50.6,167.4)	18.0 ± 6.24	(2.49,33.5)	14.3 ± 0.58	(12.9,15.8)
Medical student n=27	135.4 ± 61.1	(111.7,159.1)	20.6 ± 10.0	(16.7,24.5)	27.6 ± 35.5	(13.9,41.4)
Safety officer n=2	59.5 ± 21.9	(137.5,200.0)	15.0 ± 2.83	(10.4,40.4)	13.5 ± 0.71	(7.15,19.9)
NIOSH Bivariate panel						
Cell 1 n=33	124.1 ± 62.3	(102.0,146.2)	19.3 ± 9.40	(15.9,22.6)	22.8 ± 32.3	(11.3,34.3)
Cell 2 n=3	164.3 ± 61.8	(10.9,200.0)	18.7 ± 10.7	(7.90,45.2)	23.7 ± 16.7	(17.9,65.3)
Cell 3 n=11	120.7 ± 58.1	(81.7,159.8)	17.8 ± 5.01	(14.5,21.2)	22.9 ± 13.6	(13.0,31.3)

The N95 reported a well-fitted feeling (61.7%), perceived appropriate fit abilities (63.0%), and reported comfortable (42.6%). In contrast, the KF94 respirator had the highest perceived breathability rate (83.0%) (Table 3).

Table 3 Passed fit factors, Well-fit feeling, Appropriate fit abilities, Comfortable, and Breathable of the respirators

Variable	Respirator type N=47 (%)		
	N95	KN95	KF94
Passed fit testing	27 (57.4%)	0 (0%)	1 (2.12%)
Well-fit feeling	29 (61.7%)	7 (14.9%)	6 (12.8%)
Appropriate fit abilities	17 (63.0%)	0 (0%)	0 (0%)
Comfortable	20 (42.6%)	12 (25.6%)	14 (29.8%)
Breathable	30 (63.8%)	34 (72.3%)	39 (83.0%)
Appropriate fit abilities, comfortable, and breathable	4 (8.51%)	0 (0%)	0 (0%)

Discussion

For the fit abilities, the N95 respirator demonstrated superior fit performance compared with the KN95 and KF94 respirators.The N95 achieved the highest mean fit factor values and the highest fit test pass rate, whereas the KN95 had no passes and the KF94 had very few. Most participants reported a well-fitted feeling with the N95, while only a small proportion reported adequate fit with the KN95 and KF94. The superior performance of the N95 was attributed to its three-panel flat-fold design[11], sponge-padded nosepiece[12-13], and dual head straps[14], which had been associated with improved fit and stability. Only the N95 passed the fit test, which contrasted with some previous findings in small-faced populations[12]. This discrepancy may have been explained by differences in facial size distribution, as most participants in the present study were classified as Cell 1 of the NIOSH Bivariate Panel, whereas earlier studies included more participants from Cell 2. Nevertheless, both studies consistently identified the N95 as having the highest fit test pass rate. The participants in Cell 1 tended to score lower in specific fit criteria, such as chin positioning and respirator stability, suggesting that longer and wider facial dimensions may have improved certain aspects of fit ability.

The KN95 demonstrated a 0% fit test pass rate, consistent with previous reports[15], primarily due to poor fit at the nasal bridge, where inadequate nose wire conformity may have allowed leakage[16]. Differences from studies reporting higher KN95 pass rates[10] were likely attributable to variations in respirator models. Regarding usability, the N95 was rated as the most comfortable respirator, followed by the KF94 and KN95. Comfort was mainly

attributed to the padded nosepiece[13], dual head straps that distributed tension more evenly[17], and lightweight, hypoallergenic polypropylene material[18]. The N95 respirator was identified as having the most appropriate fit and comfortable. Previous studies supported these findings, attributing them to specific design features such as sponge-padded nosepieces[13] and dual rubber head straps[15,17]. The KF94 was perceived as the most breathable, consistent with pressure drop theory, as filtration efficiency and breathability are inversely related[19]. Although some participants reported breathing difficulty while wearing the N95, similar to previous findings[20], many still achieved high fit factor values. The Hook Mask enhances respirator fit by improving tightness and stability around the chin, straps, cheeks, and nose bridge, as a previous study reported[10]. The N95 respirator fit factor results (mean ± S.D.), classified according to the NIOSH bivariate face size classification (cells 1–3), indicated that all groups passed the fit testing, with values of 124.1 ± 62.3 for cell 1, 164.3 ± 61.8 for cell 2, and 120.7 ± 58.1 for cell 3. Therefore, the N95 respirator is applicable to individuals with small face sizes based on the NIOSH bivariate classification.

Limitations

Fit abilities and usability were assessed over a short duration and might not reflect performance during extended wear. Potential effects of prolonged use, such as respiratory fatigue, thermal discomfort, and pressure drop, were not fully evaluated and may affect user compliance. Variations in respirator design were not controlled, and the experimental setting may limit generalizability to real-world use.

Conclusions

In terms of fit abilities, only the N95 passed the fit test and demonstrated appropriate fit abilities, including the highest rate of perceived well-fit feeling. In the usability assessment, the N95 was rated as the most comfortable, while the KF94 was identified as the most breathable respirator. For the N95 respirator, participants who perceived it as less breathable tended to achieve higher fit factor scores and demonstrated a slightly higher fit test passing rate, suggesting a potential trade-off between breathability and fit performance. The N95 respirator achieved acceptable fit test results (fit factor ≥ 100) across NIOSH bivariate face size cells 1–3, demonstrating its compatibility with small face sizes.

Recommendation

For health workers with small facial dimensions, the NIOSH-approved N95 respirator is recommended for protection against airborne diseases during both aerosol-generating and non–aerosol-generating procedures due to its superior fit abilities and comfortability. Healthcare institutions should prioritize the provision of well-fitting N95 respirators and routinely implement fit testing programs. Further research is needed to evaluate fit performance and usability during prolonged use in this population.

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