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Major article

P2/N95 filtering facepiece respirators: Results of a large-scale quantitative mask fit testing program in Australian health care workers

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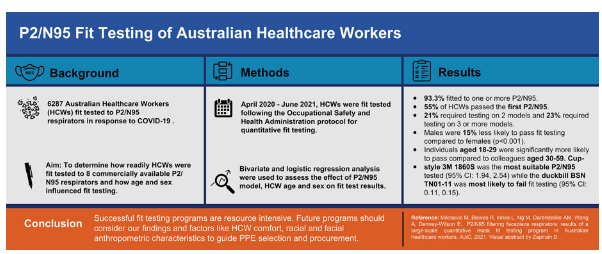

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Background: In response to the COVID-19 pandemic, 6,287 Australian health care workers (HCWs) were fit tested to N95 filtering facepiece respirators (FFRs). This study determined how readily HCWs were fitted to 8 FFRs and how age and sex influenced testing.
Methods: HCWs were fit tested following the quantitative OSHA protocol. After bivariate analysis, a logistic regression model assessed the effect of FFR model, HCW age and sex on fit test results.
Results: Of 4,198 female and 2,089 male HCWs tested, 93.3% were successfully fitted. Fifty-five percent passed the first FFR, 21% required 2 and 23% required testing on 3 or more models. Males were 15% less likely to pass compared to females ($P < .001$). Individuals aged 18-29 were significantly more likely to pass compared to colleagues aged 30-59. Cup-style 3M 1860S was the most suitable model (95% CI: 1.94, 2.54) while the duckbill BSN TN01-11 was most likely to fail (95% CI: 0.11, 0.15).
Conclusions: Current N95 FFRs exhibit suboptimal fit such that a large proportion (45%) of HCWs require testing on multiple models. Older age and male sex were associated with significantly higher fit failure rates. QNFT programs should consider HCW characteristics like sex, age, racial and facial anthropometric measurements to improve the protection of the health workforce.

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As of December 19, 2021, more than 273 million people have been infected with SARS-Cov-2 worldwide.[1] Health care workers (HCWs) are at greater risk of COVID-19 infection, particularly those in patient-facing and support roles.[2] A prospective study of over 2 million individuals in the U.K. and U.S. found that frontline HCWs were over 11 times more likely to test positive for COVID-19 when compared to the general population.[3] An estimated 19% of COVID-19 cases reported to the Centre for Disease Control and Prevention (CDC) in the U.S. between February and April in 2020 were HCWs.[4] The emergence of variants like B.1.617.2 (Delta) has seen an increased transmission rate between 40% and 70% compared with previous strains of SARS-CoV-2.[5] High levels of HCW infections, coupled with the increased transmissibility of novel variants including B.1.1.529 (Omicron) and breakthrough infections,[6] reinforces the need for robust infection control measures and appropriate use of personal protective equipment (PPE).

Growing awareness of the potential airborne transmission of SARS-CoV-2[7] informs the PPE recommendations of bodies like the CDC and Infection Control Expert Group (ICEG) in Australia. In areas of increased COVID-19 community transmission, the CDC recommends N95 respirators for aerosol-generating procedures (AGPs) and either an N95 respirator or well-fitted facemask for other patient encounters.[8] N95 respirators are disposable particulate filtering facepiece respirators (FFRs) that meet National Institute for Occupational Health and Safety (NIOSH) requirements, filtering at least 95% of airborne particles (U.S. NIOSH-42CFR84). Filtering facepiece 2, KN95 and P2 respirators are equivalent FFRs, meeting European, Chinese and Australian standards respectively.[9]

To ensure an adequate seal and maximum protection[10] NIOSH states that HCWs must be fit tested using an OSHA-accepted protocol prior to use of an FFR and annually thereafter.[11] Fit testing identifies the correct model of FFR for an individual and ensures that it is worn correctly. Quantitative fit testing (QNFT) uses an electronic device to measure the ratio of airborne particles inside to those outside an FFR.[12] There is scarce literature on large-scale QNFT programs and fewer still in the context of the COVID-19 pandemic.

In April 2020, the Sydney Local Health District (SLHD) commenced a large-scale QNFT program for at-risk HCWs in Sydney, Australia. As of June 30, 2021, over 6,200 HCWs across SLHD had been fit tested. Using data collected during this program, the aim of this cross-sectional study was to determine how readily HCWs were fitted to the available FFRs. The ability of individual FFR models to fit HCWs was examined, and the results were further analyzed based on HCW age and sex.

METHODS

Ethics

Ethics approval was granted on July 5, 2021 by the Royal Prince Alfred Hospital Research Ethics and Governance Office (Reference: X21-0130 & 2021/ETH00880).

Recruitment

A total of 6,451 HCWs aged 18-84 were fit tested between April 2020 and June 2021. Participants were excluded if they were unwilling to undertake fit testing, reported symptoms of COVID-19, had been exposed to a case of COVID-19 or were male with more than 1 day's facial hair growth.

Fit testing

Participants were fit tested using the quantitative OSHA 29CFR1910.134 standard protocol which requires an overall pass level Fit Factor (FF) of ≥100. For efficiency, the equivalent modified protocol was adopted in March 2021 as it can be completed in half the time. Fit testing was conducted using PortaCount Pro+ Respirator Fit Tester 8038 *(TSI, Minnesota, USA)* by operators who had undertaken formal training. For HCW convenience, testing was conducted indoors across multiple sites. TSI 8026 Particle Generators Model 8026 *(TSI, Minnesota, USA)* ensured adequate ambient particle counts. The FFRs tested comprised: 3M 1860, 3M 1860S, 3M 8210, 3M 8110S, 3M 1870+, BSN TN01-11, BSN TN01-12 and BYD DE2322. The first four 3M models listed are hard cup-style FFRs, while the 3M 1870+ and BYD DE2322 are flat-fold FFRs. Both BSN models are duckbill design (Appendix Table A1). HCWs were tested across the range of available FFRs until a successful test occurred. To preserve PPE, further testing of alternate FFRs was not routinely performed following a successful fit. In cases where incorrect donning technique or issues not related to the FFR were the suspected cause of failure, the HCW re-donned the FFR and testing was repeated. Where a pass was not achieved, an alternate FFR was selected for continued fit testing. FFR model selection was based on test operator experience, PPE supply levels and HCW preference. Not all FFR models were available for the entire duration of the QNFT. To conserve time and resources, FFRs showing obvious signs of ill-fit were not tested.

Resources

The QNFT program demanded human resources including the employment and training of fit test operators, time off work for HCWs to attend fit testing and database maintenance. Purchased materials included: FFRs, 13 PortaCount Pro+ units and particle generators, miscellaneous fit testing materials and the use of hospital rooms.

Analysis

HCW name and ID number recorded at the time of fit test were matched with a human resources database to obtain HCW age and binary sex. Fit tests that could not be linked with demographic (particularly, age and sex) data of HCW were excluded (n = 30). Nonbinary sex data was not available in the recruitment database. Fit tests without sufficient information on FFR model were also excluded (n = 134). HCW age at time of testing was categorized in 5 groups: 18-29, 30-39, 50-49, 50-59 and 60+.

Fit test data were dichotomized into pass (FF ≥ 100) or fail (FF ≤ 100). To determine the number of FFR models needed to find a suitable fit for a HCW, the number of failed trials for each HCW was calculated. A trial refers to a specific FFR model tested on an individual HCW and could comprise 1 or more fit tests. A trial was considered a pass provided there was at least 1 successful fit test within a trial, even when other fit tests failed. If 1 FFR model was tested multiple times and passed every time, only 1 instance of pass trial was recorded. Similarly, multiple fails for 1 FFR model was considered as 1 failed trial. Frequencies were then calculated for the number of failed trials across all HCWs.

Pass rates were calculated based on the number of passed trials as a proportion of total trials for a specific age group, sex or FFR model. Bivariate analysis was conducted to display the distribution and primary association between binary fit test results and age; sex; and FFR model determined by χ^2 tests. For assessing effect size and strength of association, a logistic regression model was fitted to binary fit test results, where independent variables were age groups, sex and FFR models. All analyses were done in *R* (version 4.0.3).

RESULTS

Demographics

A total of 6,287 HCWs had sufficient data available for inclusion (Females = 4,198, Males = 2,089). The average age of HCW was

Table 1
Distribution of FFR models across trials

FFR models	Frequencies (N)	Percentages (%)
3M 1860	3,399	29.43
3M 1860S	2,261	19.58
3M 1870+	447	3.87
3M 8110S	400	3.46
3M 8210	416	3.6
BYD DE2322	2,945	25.5
BSN TN01-11	1,363	11.8
BSN TN01-12	319	2.76
Total	11,550	100

Table 2
Number of unique FFRs requiring testing to achieve a pass trial result

FFRs required for a pass	Frequencies (N)	Percentages (%)
1	3,481	55.37
2	1,324	21.06
3	886	14.09
4	443	07.05
5	100	01.59
6	36	00.57
7	15	00.24
8	2	00.03

37.8 years. In total, these HCWs completed 11,550 fit test trials (Table 1).

Quantitative fit testing outcomes

Of 11,550 trials, 6,441 (55.8%) passed and 5,109 (44.2%) failed. On average 55% of HCWs passed the first FFR model, 21% required 2, 14% required 3 and 9% required 4 or more models to achieve a successful fit. A total of 5,868 (93.3%) of all HCWs were fitted to at least one of the available FFRs (Table 2). Both age groups and sex showed primacy of association with fit test results (Table 3), where age group 18-29 years had the highest pass rate (58.9%) and females had a higher pass rate (59.9%) than males (48.1%).

In the logistic model, HCWs aged between 18 and 29 had the highest odds of passing a trial on any given FFR, while those aged 30-39, 40-49 or 50-59 were approximately 20% less likely to pass a trial ($P \leq .001$) (Table 4). Sex was also significantly associated with trial pass rate ($P < .001$), where males were 15% less likely to pass a fit test trial (95% CI: 0.78, 0.93) compared to females (Table 4).

Fit performance of different FFR Models

The most frequently trialed FFRs were the 3M 1860 (n = 3,399, 29.4%) and the BYD DE2322 (n = 2,945, 25.5%) (Table 1). Females had higher pass rates than males across all FFR models except the 3M 1860, 3M 1870+ and 3M 8210. The 3M 8210 had the highest pass rate (83.9%) for males while the 3M 1860S had the highest pass rate for females (83.8%) (Fig 1). Several FFR models were associated with trial pass or failure ($P < .001$). The best performing FFR was the 3M 1860S, which was 2.2 times more likely to pass (95% CI: 1.94, 2.54) compared to the baseline model (3M 1860) (Table 4). The BSN TN01-11 was the worst performing FFR and was 87% less likely to pass compared to the baseline. The BSN TN01-12 and BYD N95 also performed poorly; they were 72% and 76% less likely to pass a trial compared with the baseline, respectively ($P < .001$).

Table 3
Distribution of age, gender and FFR models across trials, N = 11,550

Variables	Trials [N (%)]		
	Fail	Pass	P value (χ^2)
Age			
18-29	1,327 (41.1)	1,902 (58.9)	<.001
30-39	1,490 (45.9)	1,759 (54.1)	
40-49	869 (46.9)	984 (53.1)	
50-59	720 (46.5)	830 (53.5)	
60+	703 (42.1)	966 (57.9)	
Sex			
Female	3,008 (40.1)	4,491 (59.9)	<.001
Male	2,101 (51.9)	1,950 (48.1)	
FFR models			
3M 1860	1,109 (32.6)	2,290 (67.4)	<.001
3M 1860S	385 (17.0)	1,876 (83.0)	
3M 1870+	138 (30.9)	309 (69.1)	
3M 8110S	121 (30.2)	279 (69.8)	
3M 8210	120 (28.8)	296 (71.2)	
BYD DE2322	1,959 (66.5)	986 (33.5)	
BSN TN01-11	1,077 (79.0)	286 (21.0)	
BSN TN01-12	200 (62.7)	119 (37.3)	
Total	5,109 (44.2)	6,441 (55.8)	

Table 4
Logistic regression fitted to trial attempts by age, gender and FFR model, N = 11,550

	OR (95% CI)	P value
Age		
18-29	1.00	
30-39	0.79 (0.70, 0.88)	<.001
40-49	0.77 (0.68, 0.88)	<.001
50-59	0.79 (0.69, 0.91)	.001
60+	0.88 (0.77, 1.01)	.073
Sex		
Female	1.00	
Male	0.85 (0.78, 0.93)	<.001
FFR models		
3M 1860	1.00	
3M 1860S	2.22 (1.94, 2.54)	<.001
3M 1870+	1.09 (0.88, 1.35)	.451
3M 8110S	1.05 (0.83, 1.32)	.702
3M 8210	1.17 (0.94, 1.47)	.172
BYD DE2322	0.24 (0.22, 0.27)	<.001
BSN TN01-11	0.13 (0.11, 0.15)	<.001
BSN TN01-12	0.28 (0.22, 0.35)	<.001

CI, confidence interval; *OR*, Odds ratio.

DISCUSSION

QNFT program results

The present study investigated the results of a large-scale QNFT program launched in response to the COVID-19 pandemic. It revealed significant associations between both HCW sex and FFR model with fit test result. The program was successful with 93.3% of HCWs fitted to at least 1 of the 8 available FFRs. 419 HCWs (6.66%) who could not be fitted to an FFR were either redeployed to lower-risk settings or fitted to a reusable elastomeric respirator, which have performed significantly better than disposable FFRs.[9,13] In comparison, Winter et al found only 72% of HCWs could be fitted to any of the 3 models tested in their study of 50 Australian HCWs, even after training in correct donning technique.[14] Wilkinson et al found 89% of 5024 South Australian HCWs could be successfully fitted to 1 of 5 available FFRs.[15] Because the present study tested 8 models −− more than either the Wilkinson or Winter et al studies −− the higher percentage of successfully fitted HCWs was unsurprising. In a Norwegian study of 127 workers in the smelting industry, 96% of participants were successfully fitted with at least 1 of 14 respirators tested.[13] Final fit pass rates

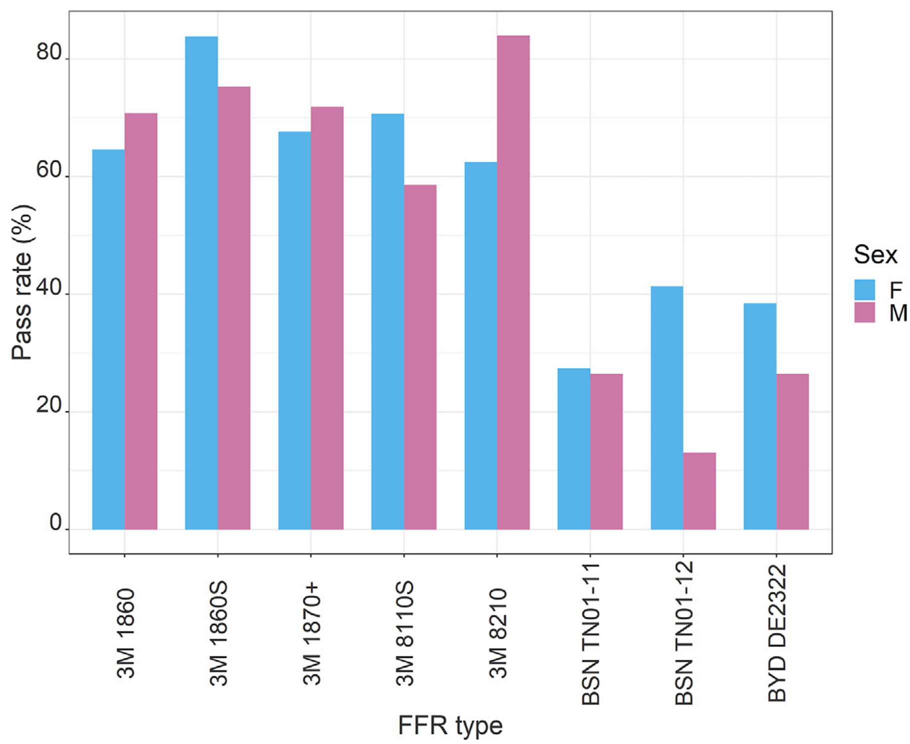

Fig 1. Fit testing pass rate by FFR model and sex.

increase as more models and sizes are tested and this was borne out in the present study.[16,17]

The success of this QNFT program must be considered alongside the failure of approximately 45% of all trials, where a single trial could comprise multiple fit tests. In the present study, only 55% of HCWs passed the first FFR model and nearly 1 quarter required fit testing on 3 or more FFR models (Table 2). Of those successfully fitted in the Wilkinson et al study, 82.9% were successfully fitted with the first tested FFR, 12.3% with a second model and 4.8% required 3 or more tests.[15] The higher initial pass rate in this study was most likely related to the delivery of PPE education to all participating HCWs and the "real-time" fit test implemented by the operators prior to the formal fit testing protocol. Carvalho et al found that 1,443 HCWs in London required a median number of 2 fit tests to identify a suitable FFR.[18] In the present study, the majority of HCWs were able to pass the first FFR tested. This incongruity was likely due to the London study's inclusion of all individual fit tests, rather than fit test trials. While the present study emphasizes the effect of the FFR model, Carvalho et al demonstrated that fit testing protocols are imperfect, frequently requiring repetition even when the FFR model being tested is suitable. Nevertheless, their findings and those of the present study demonstrate the resource intensive nature of programs which aim to protect the majority of HCWs. Consecutive fit tests require HCW time, large PPE stockpiles and multiple FFR models, scarce resources in the context of a pandemic. Access to a stable supply of fewer, more suitable FFR models could reduce this burden substantially. In the latter stages of this QNFT program, the modified OSHA protocol was adopted to enable fit testing in half the time of the standard protocol. Efficiency enhancements like these should be sought wherever possible.

FFR model and pass rate

In concordance with previous studies, there was substantial variation in pass rates between different FFR models. For females, the 3M 1860 S had the highest pass rate (83.8%) and BSN TN01-11 the lowest (27.4%) For males, the 3M 8210 passed 83.9% of trials while the BSN TN01-12 passed only 13.0% (Fig 1). In a Norwegian study, the pass rate for FFR models ranged from 19%-89%[13] and Lee et al found that 5 standard-sized FFR models fit between 8% and 95% of the participants.[19] Ciotti et al found pass rates varied significantly depending on the design of the FFR; the pass rate for flat fold FFRs was 57.5%, 18.3% for duckbill and 3.3% for cup-style models.[16] In contrast, cup-style models 3M 1860, 1860S, 8210 and 8110S were among the best-performing FFR models in the present study (Fig 1). This disparity could be explained by Ciotti et al reporting testing 4 cup-style models which were too large for the 50 HCWs included in their study, the majority of whom were female with smaller facial dimensions.[16] Lee et al reported a 75% pass rate for the 3M 1860, in line with the 67.4% pass rate of the present study.[19] Regli et al reported QNFT first fit-pass rates of 43% and 54% for TN01-11 and TN01-12, respectively.[17] In the present study, these performed substantially worse; 20.9% and 37.3%, respectively (Table 3). The demographic composition of the 72 HCWs fit tested by Regli et al was not described.[17] This, in addition to a smaller sample size, may explain the difference in pass rate. Lee et al proposed that all approved FFRs should be tested to ensure that at least 90% of randomly selected users will achieve a successful fit test with the given FFR.[19] None of the FFR models in the present study met this criterion. Similarly, Lawrence et al tested 21 FFRs on 25 participants, finding only 4 models successfully fit more than half the participants.[20]

The logistic regression model determined the suitability of fit adjusting for age and sex of HCWs, providing a more generalizable outcome. Compared with the baseline model (3M 1860), 3M 1860S showed better fit across age groups and sexes while BYD DE2322, TN01-11 and TN01-12 performed poorly. The wide range of odds ratios (ORs) found is similar to that reported by Carvalho et al across 12 FFR designs (0.09 to 1.70).[18] The ORs demonstrated that the BSN duckbill models were significantly less likely to fit HCWs when compared to the hard cup-style models (Table 4).

Sex and pass rate

Facial anthropometric dimensions have an important influence on FFR fit[15] and these measurements can vary significantly between males and females.[21,22] In the U.S., FFR design was based on a panel to fit more than 95% of American civilians.[23] Women and individuals with Asian racial backgrounds were under-represented in this panel.[9] In the present study, females were 15% more likely to pass a trial when compared with their male colleagues. To the authors' knowledge, this is the only fit testing study with results favoring females. McMahon et al found female HCWs were significantly less likely to achieve a successful fit for 1 of 6 models of FFR tested.[24] In a U.K. study published in 2021 analyzing the results of 1049 fit tests, there was a significantly higher failure rate for women than for men; 18.2% and 9.2%. respectively.[25] Similar to the McMahon et al study, the authors considered all fit tests rather than fit test trials and used a qualitative fit testing protocol. Han et al found also significant differences between 10 anthropometric dimensions between Korean males and females, and significantly increased failure rates amongst women for 2 of 3 FFRs assessed in their study.[26]

While the aforementioned studies found females were less readily fitted to an FFR, other research has found no significant difference in pass rates between males and females.[13,14,19,21,27] Foreland et al reported no significant difference in fit test pass rate between sexes, but their sample of 127 Norwegian workers included only 15 females.[13] Both Spies et al and Winter et al supported this finding, however smaller sample sizes of less than 50 HCWs were utilised.[14,21] Green et al similarly reported no difference in fit test failure between males and females. This large-scale multicenter study only considered the rate of total failure across all FFRs tested, including reusable respirator models, rendering comparison with the present study difficult.[27] Oestenstad and Bartolucci assert that while sex may have influence FFR fit, individual facial anthropometric dimensions are of greater importance.[28]

The authors of the present study propose the following explanation for this QNFT program favoring female HCWs. Twice as many females as males underwent fit testing in the present study, demonstrating the strong representation of females in the Australian health care workforce. While this demographic composition was not dissimilar to other QNFT programs,[18] the long duration of our program and the dynamic feedback of results to PPE procurement centers led to increased testing of FFR models better suited to females. For example, the 3M 1860S, the most successful FFR tested and third most frequently tested, was suited to a smaller facial type seen more frequently in females. The availability of small version FFRs in the present study across all models may have increased the likelihood of successful fit testing for female HCWs. For FFR model designs with 2 sizes, pass rates for females were higher than for males on the smaller sized models (3M 1860S, 3M 8110S and BSN TN01-12). Males had higher pass rates on larger or standard-sized FFRs like 3M 1860 and 3M 8210 but not on BSN TN01-11 (Fig 1). Additionally, the program's duration resulted in extensive fit test operator experience specific to our predominantly female sample. Wilkinson et al reported operator experience was one of the most important predictors of successful fit testing, alongside HCW facial characteristics.[15]

Age and pass rate

The present study found an association between age and fit test results. When adjusted for sex and FFR model, HCWs aged 18-29 were significantly more likely to pass a trial when compared with their colleagues aged 30-59 (Table 4). However, Wilkinson et al reported no significant difference in the proportion of successfully fitted HCWs based on age.[15] This was in agreement with findings from other studies using smaller sample sizes.[13,14] Unlike the present study, Wilkinson et al reported the total rate of failure across all FFRs tested for each age group. This may explain why no difference was found between age groups. More recent QNFT studies have not reported on age as a variable in fit testing.[17,18,27,29] Theoretically, age can influence respirator fit; Zhuang et al found statistically significant differences in facial anthropometric dimensions across almost 4000 U.S. survey respondents who were over 45 years old, when compared to workers aged between 18 and 29.[30] In the present study, 67% of fit tested HCWs were female. McMahon et al reported a significant difference in the percentage of successful tests across age groups of women, but not men for 1 FFR model.[24] Manganyi et al also found that age explained some of the variation in FFR fit for females, but not for males.[31] Our findings support these findings that age is a factor in FFR fit, however further research is warranted.

LIMITATIONS

The present study was one of the largest published single center QNFT programs. Dissemination of its findings is vital to inform the respiratory protection programs of other health care services. In the reporting, FFR model identifiers have been unaltered to allow for ease of comparison. Unfortunately, manufacturers produce multiple similar FFRs with different model numbers based on country of certification. For improved data sharing, the adoption of an internationally standardized FFR naming system is recommended.[10]

The primary goal of the QNFT program was to enhance the respiratory protection of as many HCWs as quickly as possible. Fit testing was nonuniform with extensive variation in the models of FFR, order of testing and number of fit tests between HCWs. Fit testing success is influenced by user fit checking,[32,33] training,[14,15] donning assistance,[34] consecutive donning[35] and temporal factors.[36] The results should therefore be considered in the dynamic context of the pandemic and not through the lens of traditional experimental design. The authors have attempted to account for the multiple factors influencing fit testing by reporting fit test trials rather than individual fit tests, which were adjusted for HCW demographics in the logistic regression model. A limitation of our study was that nonbinary and nondisclosed genders were not accounted for; this should be rectified in further QNFT programs. Additionally, no data were collected on HCW factors like Body Mass Index[37] and racial and facial anthropometric dimensions which are known to influence fit testing.[15,38] Face length and interpupillary distance can impact FFR fit, while nasal protrusion and breadth are also important.[30] In 2010, Oestenstad and Bartolucci found that decreasing bizygomatic breadth (face width) and menton-sellion length (face length) increased the probability of cheek leak and chin leak, respectively. The authors recommended that 3-dimensional facial scanning be used to design and select better fitting FFRs.[28] In 2021, Carvalho et al found that among 1,443 participants, White HCWs were significantly more likely to pass a fit test compared to Asian, Black, mixed or other ethnic groups.[18] Because the present study only considered basic demographic data, it does not aid the prediction of which respirator models are better suited to specific individuals. Future research analyzing the racial and facial anthropometric characteristics of a subset of the fit tested HCWs from the present study could aid the selection and design of FFRs. This could ultimately enhance the protection of our diverse health workforce.

HCW preference for specific FFR models was also not assessed. Preference for FFR is important because discomfort is linked with reduced compliance, increased doffing and reduced efficacy.[39] Anecdotally, HCWs in the present study expressed greater discomfort when wearing rigid cup-style FFRs, a finding reflected in a recent Australian study assessing HCW knowledge and attitudes to a respiratory protection program.[40] Finally, the logistical and financial implications of QNFT programs like that of the present study demand future consideration. While the present QNFT program consumed considerable human and material resources, these were not quantified over the course of the study, nor could this data be acquired retrospectively. This substantially limits the ability of our study to guide other health services when assessing the feasibility of their own respiratory protection programs. Where possible, HCWs should be prioritized based on risk of exposure and efficiency gains be implemented with respect to operator training, FFR selection and procurement.[9]

Fit testing and COVID-19

The pandemic has highlighted a need for improved protection of HCWs. While the number of global SARS-CoV-2 HCW infections remains unknown, in the related Middle East Respiratory Syndrome and SARS-CoV-1 epidemics, HWC infections accounted for approximately 13.37% and 21.07% of total cases respectively.[41] During a second wave of COVID-19 in the state of Victoria, Australia, at least 70% of HCW infections were acquired in the workplace.[42] Despite the development of effective vaccines since then, breakthrough infections of fully-vaccinated HCWs wearing surgical masks have been reported, resulting in patient mortalities.[6]

Bodies including the CDC, ICEG and Public Health England now recommend FFR use in high-risk clinical settings even in the absence of AGPs.[39,43,44] However, the efficacy of fit testing in reducing the transmission of SARS-CoV-2 is unknown. In a systematic review by Long et al in March 2020, FFRs were not associated with a statistically significant lower risk of laboratory confirmed influenza, viral infection or respiratory illness when compared with the use of surgical masks.[39] In a well-conducted laboratory simulation, Noti et al found tightly sealed FFRs blocked 99.8% of total virus while poorly-fitted FFRs blocked only 64.5%, even less than a loosely fitted surgical mask.[45] In the future, assessment of fit tested HCW infections will provide insight into the efficacy of the QNFT program. Compared to the health sector, fit testing is more routine in mining and construction industries. While the OSHA protocol accounts for movement in the overall fit-factor, this may be inadequate for the activities performed by HCWs. In 2017, Suen et al found that fit-factors provided by FFRs dropped significantly following nursing procedures and fell below the pass level for one-third of participants.[46] Hwang et al found that 73% of HCWs were not adequately protected when performing chest compressions while wearing successfully fit tested FFRs.[47] As fit testing of HCWs becomes routine practice, the consideration of testing protocols more specific to health care is warranted.

The QNFT program formed a key part of respiratory protection program implemented by SLHD in accordance with Clinical Excellence Commission guidelines at a state level. Other components included: risk assessment and management, education, vaccination program and compliance and the appropriate use of all PPE including eye protection. Central management of FFR stock, in accordance with a sustainability management plan, ensured ongoing adequate supply. In accordance with state guidelines, all HCWs were trained in the correct usage of FFRs which emphasized the importance of fit checking FFR seal at each use. HCWs were provided a card identifying their fitted FFR and informed of the need for repeated testing should they undergo large fluctuations in weight, dental surgery or suffer facial trauma. Those in the highest risk settings were scheduled for follow-up testing 1 year after their initial fit. The use of PPE was considered only as 1 component of a hierarchy of controls to reduce the transmission of SARS-CoV-2.

CONCLUSIONS

In this large-scale QNFT program involving over 6,200 HCWs, younger individuals were significantly more likely to pass fit testing and females were 15% more likely to pass compared to males. Cup-style FFRs like the 3M 1860S were most suited to the HCWs in the study. To successfully fit the vast majority of HCWs, substantial resources were required with almost half of HCWs requiring testing on at least 2 of 8 available models. It is the researchers' hope that these findings guide PPE selection and procurement by other health services in the future. QNFT programs should consider HCW characteristics like FFR comfort, sex (including nonbinary), racial and facial anthropometric measurements to improve the respiratory protection of the health workforce.

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APPENDIX

Appendix Table A1
Description of FFRs included in the QNFT program

Manufacturer	Model	Design	NIOSH approval (TC) number
3M	1860	Hard cup-style	84A-0006
3M	1860S	Hard cup-style	84A-0006
3M	8210	Hard cup-style	84A-0007
3M	8110S	Hard cup-style	4A-0007
3M	1870+	Flat-fold	84A-5726
BSN	TN01-11	Duckbill	84A-3348
BSN	TN01-12	Duckbill	84A-3348
BYD	DE2322	Flat-fold	84A-9221

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