# Evaluation and comparison of N95 masks with Modified Snorkel Masks and Positive Air Pressure Respirators (PAPR) in Healthcare Workers

D. Clinkard, A. Mashari, K. Karkouti, L. Fedorko.

Department of Anesthesia and Pain Management, Toronto General Hospital, University Health Network. 600 University Ave, Toronto, Ontario, Canada.

Corresponding Author:

David Clinkard

david.clinkard@mail.utoronto.ca

Department of Anesthesia and Pain Management, Toronto General Hospital, University Health Network. 600 University Ave, Toronto, Ontario

Keywords: N95, Snorkel Mask, PAPR

## Summary

Disposable N95 respirator masks are the current standard for health care worker respiratory protection in the current SARS-CoV 2 (COVID 19) pandemic. However, initial fit testing can have low sensitivity, leading to inconsistent protection. Multiple groups have developed alternative solutions, such as modified snorkel masks to overcome these limitations, however validation of these solutions has been lacking.

We sought to determine if N95s and Snorkel Masks (SM) equipped with filters provide consistent protection levels in healthcare workers and if the addition of a positive pressure via an inexpensive powered air purifier respirator (PAPR) to the SM can enhance protection. 51 Health care workers who were qualitatively fitted with N95 masks underwent quantitative mask fit testing according to a Simulated Workplace Protocol (SWP). N95, SM and SM with the addition of a novel inexpensive PAPR (PSM) were tested. Utilizing a standardized seven-step SWP, respiratory filtration ratios were collected for each individual step, and averaged to obtain overall fit factor (SWPF). Failure was defined as individual filtration ratio or overall SWPF below 100.

N95s and SM failed one or more testing steps in 59% and 20% of participants, respectively. 24% of N95 and 8% of SM failed overall SWPF. The PSM had zero individual or overall failures. N95 and SM respirators were found to provide inconsistent respiratory protection in experienced health care workers. These findings suggest that qualitative N95 testing may overestimate respiratory protection, and that a quantitative assessment of N95 fit significantly improves the consistency of respiratory protection.

## Introduction

The burden of SARS-CoV 2 infections among health care workers continues to exceed that of the general community[1,2,3]. This could be due to knowledge gaps regarding route of transmission and infectivity,[4] or failures of our personnel protection systems.

Half face respirators such as single use N95 respirators (N95s) are widely used for protection of North American health care workers from respiratory pathogens including SARS-CoV 2. However, recent meta-analysis suggest that N95s have failed to significantly reduce infections among health care workerss compared to standard surgical masks[5,6]. Available studies also suggest that N95s may not provide consistent performance, even after standardized fitting and training[7,8]. Taken together, this suggests that either SARS-CoV 2 has other significant routes of transmission, in addition to droplets and aerosols, against which HCWs are not adequately protected, or that N95 respirators do not provide adequate protection against droplets and close-range aerosols.

The performance of N95s and other negative pressure respirators primarily depends on a stable face seal to prevent entrainment of unfiltered air[9]. Consistency of this seal is essential to protect health care workers, particularly anaesthetists. Anaesthetists are highly involved in the management of COVID patients; serving on rapid response teams, as well as delivering care in the operating room and ICU, all roles that involve high levels of aerosolizing procedures and COVID exposure[10].

Limited supply of N95 respirators has led to the development of alternative methods of respiratory protection, including altering commercially available masks designed for other industries and applications, potentially resulting in inconsistent protection. Modified snorkel masks (SM)with attached high efficiency filters[11] are a particularly attractive option because they are widely available and offer full-face protection. However snorkel maskss, like N95s require a stable facial seal. In the absence of rigorous testing[12], snorkel maskss may provide a false sense of security to HCWs.

Powered air-purifying respirators (PAPRs) are considered gold standard when dealing with virulent airborne pathogens[13], and were utilized extensively by the Chinese airway teams, and may have led to the low health care worker infection rate seen in Wuhan [14]. Unfortunately, availably have precluded their widespread use in the current pandemic. Further modification of snorkel masks with a small inexpensive fan to provide filtered positive purified air pressure and convert this into a Powered air-purifying respirator could potentially overcome the requirement of a consistent facial seal and may provide superior protection.

We sought to determine the failure patterns and filtration efficacy of single use N95s, snorkel masks with a high efficiency filter, and snorkel masks equipped with a powered air-purifying respirator in healthcare workers.

## Materials and Methods

After obtaining institutional review board approval, 54 health care workers previously qualitatively fit tested and trained on disposable N95 masks by the institutional occupational health department within the past year were recruited.

After informed consent, participants were quantitatively assessed for mask fit and filtration ratios under three conditions (N95, SM, PSM) using Aerosol Condensation Nuclei Counter Quantitative Fit Testing method (AccuFIT 9000, AccuTech Analytics). The Canadian Standards Association Z94.4 Simulated Workplace Exercise Protocol (SWP) for respirator selection was followed[15]. The protocol includes seven separate steps: quiet breathing, deep breathing, moving the head side to side, moving the head up and down, speaking, bending forward and backward, and quiet breathing again. For each step, particle concentrations of 0.2 to 1 µm were measured inside the respirator and compared to ambient concentrations, and an individual filtration fraction of outside/inside concentration (IFF) was generated. Individual filtration factor measures for the 7 steps were then harmonically averaged to provide the Simulated Workplace Exercise Protocol Factor (SWPF). The Canadian Standards Association SWPF minimum standard for N95 is 100[14]. IFF or SWPF of less than 100 was deemed a ‘failure'.

Participants were first tested using their institutionally fit-tested model of N95s. All participants were given new masks for the experiment. The SWP was then repeated for the PSM and SM conditions.

The SM (Aria Ocean Reef, California, U.S.A) utilized Air-Guard filters (Model 179-0000, filter efficiency >99.9999%, Intersurgical, UK) connected via an adaptor similar to previously published designs[11].

The powered air-purifying respirator was constructed utilizing 18v rechargeable batteries (Ryobi, Japan), and an off-the-shelf brushless motor fan (UTUO Brushless Radial Blower) capable of generating an average of 2 cmH2O pressure inside the mask. Urethane enclosures were cast using custom designed 3D-printed molds created by our team. Two Air-Guard filters (Intersurgical, UK) were connected in parallel to the blower and standard 22 mm anesthesia tubing and one-way valves were utilized for connections (Fig. 1). All components designed by our team are released under the CERN-Open Hardware License 2.0-Strongly Reciprocal. All files and data are available at https://github.com/tgh-apil/PAPR .

Participants were asked to rate on a 1-5 scale, the comfort, ease of donning and doffing and the overall usability of each PPE solution. Data was with parametric (paired t-tests) and non-parametric tests (Friedman) as appropriate, with the threshold for significance set at 0.05 (GraphPad Software, La Jolla California USA)

## Results

54 subjects were enrolled and 51 completed the testing. Three subjects withdrew from the study due to time constraints and were excluded from the analysis. A total of 357 testing steps were performed on each PPE device. The mean age was 46.5 years (SD=11.5), with 52% of participants identifying as female. Mean BMI was 25.8 (SD=4.3, 18.5-36.5) (Table 1).

Powered and unpowered snorkel mask performed significantly better than N95s (Fig 2). There was a substantial failure rate with N95s and unpowered snorkel masks; on N95s 59% of participants failed an individual step and 35% failed the overall test. On the unpowered snorkel mask 20% of participants failed an individual step, 8% failed overall. Importantly, 24% of participants passed the overall teston their disposable N95, while failing individual steps. Similarly, 12% of the unpowered snorkel mask users passed the overall test while failing on individual steps. Addition of a powered air-purifying respirator to the snorkel maskeliminated both individual and overall failures. (Fig. 3)

Comfort was significantly greater with the PAPR (3.92 ± 1.38) as compared to the disposable N95 (3.14 ± 1.24) or SM (2.94 ± 1.23). PAPRpracticality and usability (3.14 ± 1.22) was rated significantly greater than both N95s (2.54 ± 0.98) and unpowered snorkel mask (2.64±0.97). There were no significant differences between the respirator types for ease of donning or doffing (N95 3.45±1.11; SM 3.56±0.97; PSM 3.58±0.97).

## Discussion

The main finding of this study is that qualitatively fit N95s and unpowered snorkel maskSM devices have significant protection failures, and do not provide consistent protection in well trained and tested health care workers.

Current mask fit testing protocols can be broadly divided into qualitative and quantitative methods. Qualitative methods rely on detection of a bitter substance such as “Bitrex”, while quantitative fit testing calculates an internal to external particulate ratio, which is then mathematically averaged to provide a “pass”.

In this study, 35% of participants who had previously passed the institutional qualitative fit testing and been trained on the use of N95s within the previous 12 months (most within the previous month), failed the overall quantitative fit test.

Given that viral exposure can occur at any individual mask fit failure point, our observations suggest that current qualitative respirator fit protocols, as well as quantitative protocols that focus on averaged values (such as the Canadian protocol (Z94.4) and US (NIOSH) equivalent), have limited relevance when dealing with biological agents. Currently, a “Pass” relies on exceeding an average predetermined value, instead of ensuring all individual steps exceed this value. However, even of those participants who passed the overall quantitative test, 24% still failed one or more individual steps such as talking or bending over. This suggests that subjectively fit-tested disposable N95s may not provide consistent protection against respiratory aerosols in HCWs.

The unpowered snorkel masks demonstrated improved consistency compared to an N95 but were also not completely reliable. While the overall test failure rate was much lower (8%), 12% of unpowered snorkel mask users still passed the overall test despite failing an individual step. The risk posed by these failures in the unpowered snorkel mask device may be greater than that posed seal breaches in N95s. A study by Zhu et al suggests that when utilized in the health care environment, an unnoticed seal leak in an elastomeric respirator may paradoxically result in worse protection than an N95[9]. Together, these findings suggest that significant caution should be exercised when considering the use of repurposed snorkel masks for high-risk clinical situations. Our data show however that the risks associated with modified snorkel masks can be significantly mitigated with the addition of an inexpensive fan and filter providing a small amount of positive pressure.

A key focus of our efforts was minimizing costs, to allow widespread utilization. We estimate the average unit cost to manufacture 1000 of these modified snorkel masks with PAPR attachment is under $250/CAD. While far more expensive then N95s ($2-5/CAD) or a modified unpowered snorkel mask (~$100 CAD), this is far less than a purpose built PAPR ($1000-2500/CAD), while providing comparable protection and the ability to be reused multiple times.

A limitation of this study is its single center design and limited sample size. To achieve NIOSH standards, a morphometric fit panel is usually required, and ideally the mask could be tested on the ISO digital head forms [16]. As we did not have access to the morphometric fit panel, to mitigate this risk, we sought to ensure a diverse ethnic sample, and used a sample size that exceeds what previously has been recommended (35-40) for respirator fit test panels [17].

The goal of PPE is to protect every HCW and to minimize the risk of infection. Current negative pressure respirators such as N95 fit via qualitative means, and SM demonstrated significant protection limitations in the current investigation. The optimal PPE strategy for aerosolized vectors minimizes potential faults in mask fit, allowing consistent protection, which as noted, is critical when dealing with a biological vector, as even a single particle may result in infection. Quantitative fit testing that focuses on “passing all steps” as opposed to passing overall, can help identify individual fit faults, and guide N95 mask choice to allow the achievement of consistent N95 respirator fit. Alternatively, the addition of filtered positive pressure can mitigate this issue, providing users with optimal respiratory protection.

## References

1. CDC COVID-19 Response Team. Characteristics of Health Care Personnel with COVID-19 United States, February 12–April 9, 2020. Morbidity and Mortality Weekly Report. Vol 69. April 14, 2020 ed2020:477 - 481.

2. Chou R, Dana T, Buckley DI, Selph S, Fu R, Totten AM. Epidemiology of and Risk Factors for Coronavirus Infection in Health Care Workers: A Living Rapid Review. Ann Intern Med. 2020.

3. Tran K, Cimon K, Severn M, Pessoa-Silva CL, Conly J. Aerosol generating procedures and risk of transmission of acute respiratory infections to healthcare workers: a systematic review. PloS one. 2012;7(4):e35797.

4. Bahl P, Doolan C, de Silva C, Chughtai AA, Bourouiba L, MacIntyre CR. Airborne or droplet precautions for health workers treating COVID-19? J Infect Dis. 2020.

5. Smith JD, MacDougall CC, Johnstone J, Copes RA, Schwartz B, Garber GE. Effectiveness of N95 respirators versus surgical masks in protecting health care workers from acute respiratory infection: a systematic review and meta-analysis.CMAJ 2016;188(8):567-574.

6. Bartoszko JJ, Farooqi MAM, Alhazzani W, Loeb M. Medical masks vs N95 respirators for preventing COVID-19 in healthcare workers: A systematic review and meta-analysis of randomized trials. Influenza and Other Respiratory Viruses. 2020.

7. Hon CY, Danyluk Q, Bryce E, et al. Comparison of qualitative and quantitative fit-testing results for three commonly used respirators in the healthcare sector. Journal of Occupational and Environmental Hygiene. 2017;14(3):175-179.

8. Lee SA, Grinshpun SA, Reponen T. Respiratory performance offered by N95 respirators and surgical masks: human subject evaluation with NaCl aerosol representing bacterial and viral particle size range. The Annals of Occupational Hygiene. 2008;52(3):177-185.

9. Zhu J, He X, Guffey S, Wang L, Wang H, Cheng J. Performance Comparison of N95 and P100 Filtering Facepiece Respirators with Presence of Artificial Leakage. Annals of work exposures and health. 2020;64(2):202-216.

10. Chou, Roger, et al. Epidemiology of and Risk Factors for Coronavirus Infection in Health Care Workers: A Living Rapid Review. Annals of Internal Medicine (2020).

11. Prakash M. Pneumask: Resuable Full-Face Snorkel Mask PPE Project. [https://bioengineering.stanford.edu/pneumask-reusable-full-face-snorkel-mask-ppe-project. [Cited 2020](https://bioengineering.stanford.edu/pneumask-reusable-full-face-snorkel-mask-ppe-project.%20%5BCited%202020), May 8].

12. Greig PR, Carvalho C, El-Boghdadly K, Ramessur S. Safety testing improvised COVID-19 personal protective equipment based on a modified full-face snorkel mask. Anaesthesia. 2020. Forthcoming.

13. Rengasamy, A., Zhuang, Z., Berry, A. Respiratory protection against bioaerosols: a literature review and research needs. American Journal of Infection Control. 2004;32(6): 345-354.

14. Zhang, Hong-Fei, et al. "Response of Chinese anesthesiologists to the COVID-19 outbreak." *Anesthesiology: The Journal of the American Society of Anesthesiologists* 132.6 (2020): 1333-1338.

15.. CSA Group. CAN/CSA-Z94.4-18: Selection, use, and care of respirators. Canadian Standards Association / Natoinal Standard of Canada. 5th Edition. Sept 2018.

# 16. Center for Disease Control. NIOSH Anthropometric Data and ISO Digital Headforms. http:// <https://www.cdc.gov/niosh/npptl/topics/respirators/headforms/default.html>. [Cited 2020, July 15]

17. Landsittel, D., Zhuang, Z., Newcomb, W., & Berry Ann, R. Determining sample size and a passing criterion for respirator fit-test panels. Journal of Occupational and Environmental Hygiene. 2014, 11(2), 77-84.

Captions

Figure 1: Modified Snorkel Mask with added positive air purifier. Masks were connected via standard 22 mm anesthesia tubing with one-way valve to a case housing a 12-volt brushless fan powered by 18 V battery. High efficiency filters are housed inside the case, which allows easy replacement.

Figure 2: Average simulated workplace protection factor (SWPF) for 51 participants wearing N95s (Mean 292.1±477, Median 144), Modified Snorkel Masks (SM), Mean 4457 ± 4418, Median 2939, and Pressurized Modified Snorkel Masks (PSM) Mean 16898 ± 15152, Median 12177. SM and PSM had significantly greater protection scores then N95s (p<0.05).

Figure 3: Individual results for 51 participants wearing N95, SM, and PSM respirators undergoing a 7-step workplace exercise protocol. Results are harmonically averaged to provide an overall simulated workplace protection factor. Green boxes represent filtration ratios ≥100 (Pass), red boxes represent filtration ratios <100.