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An Innovative Approach to Evaluating Protection Level of Tight-Fitting PAPRs when Face Seal Is Compromised

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ABSTRACT

Few studies have been done to investigate the ability of tight-fitting Powered Air Purifying Respirators (PAPRs) to compensate for face seal leaks, and this project developed an innovative approach to evaluating the protection level of PAPRs when the face seal is compromised. For this study, a cross sectional area of seal leaks versus a reduction in protection factor was used to evaluate the potential effect of a simulated leak on PAPRs during over breathing whilst exercising on a bicycle.

It was found that the ability of PAPRs to maintain positive pressure cannot be assessed by constant-flow measurement or by the sinusoidal profile of a breathing machine, however it can be assessed by collecting pressure data from inside the mask during TIL human exercise and analysing the cumulative “weight” of the negative-pressure events. Furthermore, the pressure fluctuation representing Work of Breathing does not show as much variation as the variation of the mask leakage, and some PAPRs have even larger pressure variation in comparison to the negative-pressure masks. It was concluded that the PAPRs tested are not so much breathing-assisting respirators as they are mask-leak compensation devices. PAPRs can provide additional face seal protection to the wearer in the event of mask leakage. Some PAPRs significantly outperformed the Air Purifying Respirators (APRs) (by 1900 times) whilst others minimally exceeded the protection of APRs (by 2 times) with a greater pressure variation (caused by the breathing resistance due to motor/impeller inertia) during the breathing cycles at high workloads.

Keywords: PAPR, APR, Powered Air Purifying Respirators, PAPR test, over breathing, flow, face seal, face fit, mask seal, protection factor, inhalation, exhalation, mask pressure, breathing resistance, Work of Breathing, positive pressure, motor, impeller, breathing machine, TIL test

Demonstration of a Reusable Mask in a Tubular Design that Provides Universal Fit and Protection from Respiratory Hazards

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ABSTRACT

Background: There is a well-documented need for a reusable, high-performing face mask for use by the public as a barrier to respiratory hazards.
Objective: This utility validation study sought to assess the functionality of a tubular-shaped, textile-based solution to enable the simple manufacture of a reusable face mask designed to minimize leakage and to achieve high levels of community protection from respiratory hazards.
Methods: We used a mechanistic approach to design, develop, and combine engineered components into an integrated tubular solution. To ensure the desired features were optimized when integrated, after reprocessing we tested the entire mask, as worn, for physiological impact, comfort, filtration efficiency, and leakage. For several features, the novel design and tubular shape required in-house design and manufacture of new test equipment. We tested fabrics, prototypes, and reprocessing protocols in-house and with academic partners. Independent testing for certain features was available (e.g., EN14683 Medical Face Masks, ASTM F3502-21, Standard Specification for Barrier Face Coverings) and was used to confirm performance.
Results: The tubular shape, special seals, unique harness, and three-layers of fabrics with distinct functions and composition work together to minimize leaks and ensure durability after repeated laundering. In-house testing indicated that designing a textile-based, tubular-shaped face mask optimized for source control with minimized leakage also resulted in wearer protection properties, even after hundreds of laundering cycles. Independent testing of one filter choice (Filter B) after 50 laundering cycles confirmed low breathing resistance (4.9 mm H_2O/48 Pa) and high filtration efficiency (96%) to ASTM F3502-21.
Conclusion: This utility validation study concludes that a reusable, tubular-shaped, textile-based face mask is capable of a universal fit as well as filtration efficiency and breathability performance levels that are similar to those for a disposable filtering facepiece respirator.

Keywords: Reusable mask, Filtration, Universal fit, Leakage, Breathability, Barrier face covering, Source control, Filtering facepiece respirator, Gaiter, Tubular face mask.

Assessment of a Novel Low-Cost Personal Respirator Evaluation Device

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ABSTRACT

Background: Throughout the COVID-19 pandemic, respirators and masks have been recommended, and in many instances mandated, across the globe. The National Institute for Occupational Safety and Health (NIOSH) is the main regulatory agency for respirators in the United States. Currently, the TSI 8130A and the ATI 100Xs machines are utilized for respirator filtration and resistance testing, but both are costly and valued upwards of U.S. $100,000.

Objective: The goal of this study was to develop a low-cost respirator evaluation mechanism (LREM) to evaluate respirators as well as masks and other materials for filtration efficiency (FE), inhalation resistance (IR), and exhalation resistance (ER). The aim of this mechanism is to support the development of innovative and alternative respirator and mask designs and materials with an inexpensive and more accessible testing device.

Methods: The methods and design for the LREM were based on U.S. 42 CFR Part 84 Subpart K and the corresponding standard testing procedures for air-purifying respirators published by NIOSH. The LREM itself is constructed from available components and functions to deliver sodium chloride (NaCl) aerosols in a stream of airflow to challenge a respirator or mask sample. A variety of respirators, masks, and materials were tested on both the LREM and an ATI 100Xs to assess how the LREM compares to one of the current evaluation devices.

Results: Overall, the LREM offers promise as an accessible and low-cost testing option. The LREM can accurately determine the pass/fail status of the N95 filtering facepiece respirators (FFRs) samples tested for both IR and FE based on NIOSH criteria. For all respirators, masks, and materials tested, the LREM and ATI 100Xs both show similar performance trends as seen by rankings of sample performance.

Conclusions: The LREM was constructed for approximately 6% the cost of current respirator testing gold standards. The LREM could serve as a first pass testing method done before official respirator testing (e.g. per NIOSH mandated testing) and can be particularly useful in the development of innovative respirators and masks or in testing alternative materials for each.

Keywords: COVID-19, respirator, mask, respirator testing, filtration efficiency, inhalation resistance, exhalation resistance.

Enhanced Duration SCBA

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ABSTRACT

Background: The Open-Circuit Self Contained Breathing Apparatus (SCBA) has been used for almost a century in the fire service worldwide and contributed to keeping firefighters safe as well as enhancing their performance. Several improvements have been made over the years; however, the air flow pattern is still the same as it was one hundred years ago. All the exhaled air is vented to the surroundings, including the air that has not participated in the oxygen/carbon dioxide exchange in the lungs. It is the purpose of the presented concept to change the breathing pattern with the goal to make the SCBA more efficient.
Methods: With every breath we take, some of the exhaled air comes from the mouth and trachea and has not entered the lungs for the oxygen/carbon dioxide exchange and is consequently possible to re-breathe. If a breathing mask with valves is used, the amount of re-breathable air can be increased by the air contained in the nose cup and adjacent cavities in the end of the inhalation. In average, 0.4 -0.5 liter of air, which in current technology units is wasted, has full oxygen content and only insignificant amount of carbon dioxide and can be reused. By capturing the unused air in a reservoir in the beginning of the exhalation and re-using it for the next breath, the air consumption can be substantially reduced. By re-using the air as described and always keeping the gas concentrations within acceptable limits it is estimated that the Duration/Weight (D/W) ratio for a SCBA can be increased by 50-100%, compared to present technology, depending on the degree of electronics sophistication.
Results: A human pilot test with a laboratory prototype without any advanced electronics has been performed at Duke University, NC, USA, and an increase in D/W ratio of 30% was recorded, indicating that the concept has merits.
Conclusion: The actual working duration for current SCBA can vary enormously depending on the physiology of the wearer, the task being performed, and the operating environment. It is not uncommon for 30-minute rated sets to be exhausted in 15-20 minutes. The new technology can give the firefighter more duration and extra reserve in case of getting trapped or disorientated, without increased weight.

Keywords: SCBA, firefighter, duration, weight, air-saving, hybrid, reservoir, re-breathing.