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QUANTITATIVE ASSESSMENT OF FACEMASK PERIPHERAL LEAKAGE

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SUMMARY: Peripheral air leakage affects the ability of a facemask to protect a wearer from exposure to airborne contaminants. Leakage occurs when air bypasses a mask's filter material and enters or exits the mask through gaps between the mask and the face. A wearer creates a negative pressure inside the mask during inhalation and a positive pressure during exhalation. These pressure differentials draw air in, or push air out of the mask reducing the effectiveness of a facemask. An air-pressure measurement chamber was developed to simplify mask air leakage assessments. Changes in air pressure and airflow were recorded using a differential manometer and a digital thermoanemometer. Differences between mask airflow and airflow through an open configuration (control) determined the airflow deficit driving peripheral leak-age. Four facemask types were tested including a surgical mask, a covid mask, a cotton mask and a N95 mask. The data showed leakage similarities among the four mask types tested. The surgical mask exhibited 50% leakage. The covid mask exhibited 67% leakage while the cotton mask exhibited 63%. The N95 mask exhibited a leakage of 72%. The results of this study con-firm previous studies that show high levels of peripheral leakage associated with most face-masks currently in use. The assessment method described in this study provides a new and simplified method to determine such leakages.

Key words: *facemasks, peripheral leakage, simplified assessment methodology, public health*

BACKGROUND

Facemask Leakage

Protection provided by facemasks has been investigated extensively since the outbreak of the Covid-19 pandemic. These studies have focused primarily on mask filtration efficiencies ra-ther than peripheral leakage *(Smith et al., 2016, Mueller et al., 2020, Ueki et al., 2020)*. How-ever, peripheral leakage is a major contributor to airborne droplets entering and exiting the respiratory system reducing the protection provided to a wearer. Therefore, it is important to recognize that the effectiveness of a face mask depends not only on the efficiency of the filter material but also the fit of the mask on the face. While low filter porosity is associated with better filtration, this will lead to higher differential pressures inside the mask that increases peripheral leakage *(Howard et al., 2021, Rengasamy et al., 2014, He et al., 2014)*. The periph-eral leakage resulting from different types of face shapes and filter porosities are of particular interest to public health since it influences the overall protection masks can provide. Current face masks attempt to reduce peripheral leakage by tightening the rubber straps around the head. Figure 1 illustrates the strap configurations associated with a standard surgical mask and a N95 facemask. The strap tension determines the pressure on the nose, cheeks and chin that can lead to discomfort.

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A B

Figure 1. Elastic strap configurations used for surgical face masks (A) and N95 face masks (B) to limit peripheral leakage

Slika 1. Konfiguracije elastične trake koja se koristi za kirurške maske za lice (A) i N95 maske za lice (B) za ograničavanje perifernog curenja

TESTING METHODS

Documenting peripheral leakage helps when attempting to compare the performance of different types of face masks. Masks with lower leakage are considered more effective at protecting both the wearers and those around them than masks with higher leakage. Testing facemask leakage currently includes qualitative testing and quantitative testing *(Tuomi, 1985, Coffey et al., 2002, OSHA, 2016, ISO, 2017)*. The qualitative tests are generally simple, but are subjec-tive, and provide only a pass/fail result. Quantitative tests are more objective, fairly precise, and provide numerical data. Figure 1 illustrates examples.

Qualitative Leakage Tests

Two qualitative leakage tests are generally in use today. They require a participant to wear a hood which is then filled with an aerosol that can be smelled or tasted by the wearer. The fol-lowing steps are involved in these tests:

- The facemask wearer inside the hood is exposed to an aerosol while performing a se-ries of movements and speaking exercises. If the wearer can smell or taste the aero-sol while wearing the mask, the mask fit is considered inadequate. The evaluation outcome is a “No”.
- The facemask wearer inside the hood is exposed to stannic chloride smoke while also performing exercises. If the wearer can detect the smoke, the mask fit is considered inadequate. The outcome is a “No”.

Quantitative Leakage Tests

There are currently four quantitative approaches used in evaluating mask leakage:

- The PortaCount Test: A particle-counting device measures the concentration of particles inside and outside of the mask while the wearer performs a series of exercis-es. The difference in particle count between the inside of the mask and outside of the mask is reported as a percentage (%).
- The Controlled Negative Pressure (CNP) Test: A mask is attached to a machine that creates a controlled negative pressure inside the mask. The machine measures the amount of air leaking into the mask.
- The Ambient Aerosol Condensation Nuclei Counter (CNC) Test: Similar to the PortaCount test, this method uses a CNC to measure the concentration of aerosol particles inside and outside the mask.
- The Fit Factor Measurement method using Fluorescent Particle Technique: Fluorescent particles are sprayed around the mask, and a specialized device measures the concentration of these particles inside and outside the mask.

X Y

Figure 2. Illustration of a qualitative test injecting an aerosol into the hood while the wearer performs some speaking exercises (X), and a PortaCount test which is a quantitative mask leak-age test comparing particle counts between the inside and outside of the face mask (Y)

Slika 2. Ilustracija kvalitativnog testa ubrizgavanja aerosola u kapuljaču dok nositelj izvodi neke govorne vježbe (X) i PortaCount testa koji je kvantitativni test curenja maske koji uspoređuje broj čestica unutar i izvan maske za lice (Y)

METHODS AND PROCEDURES

Instrumentation

A simplified air-pressure-air flow measurement system shown in Fig. 3 was used to investigate peripheral facemask leakage for four face mask types. All samples tested were 10 cm x 18 cm in size. All edges were taped securely to the chamber to prevent peripheral air leakage. Chang-es in face mask airflow resulting from associated differential air pressure values were documented. Pressure changes were recorded using a differential manometer and airflow changes were recorded using a thermoanemometer. Differences between air flow through the filter material and airflow without a filter material (control) defined the resulting peripheral leakage.

Functionality Tests

System functionality tests were carried out by assessing the relationship between the air flow and chamber pressure changes resulting from resistance imposed by the face mask filter mate-rials. Four layers of cotton fabric were used in the functionality tests. A 99.6% correlation be-tween changes in face mask air flow and changes in differential pressure was seen. These re-sults confirm that measured chamber air flow was linked directly to the differential pressure values. The linear correlation between differential pressure and air flow confirms the function-ality of the testing method. The results are shown in Fig. 4.

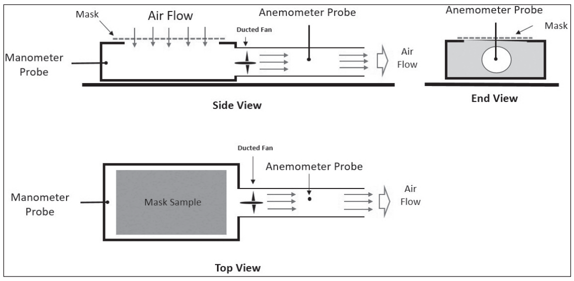

Figure 3. Schematic illustration of the air-pressure-air-flow measurement system used in esti-mating peripheral leakage

Slika 3. Shematski prikaz sustava mjerenja tlaka zraka i protoka zraka koji se koristi u procjeni perifernog propuštanja

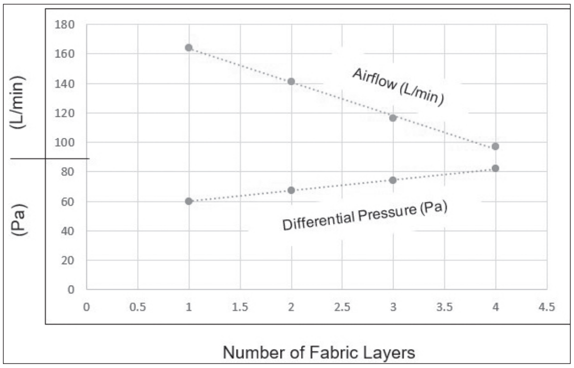

Figure 4. Relationship between air flow and differential pressure for four layers of cotton fabric filter material

Slika 4. Odnos između protoka zraka i diferencijalnog tlaka za četiri sloja filtarskog materijala od pamučne tkanine

FACEMASKS

The reduction of air flow created by the mask filter materials was documented for four face-mask types. The four face masks are illustrated in Fig. 5.

Protocol

The test chamber air fan was set at velocities of 199L/min, 259L/min, 335L/min, and 360L/min. Each mask was tested for the four air velocity conditions. The difference between the airflow measured for the open (control) configuration and the air flow measured for the face mask filter fabric determined the theoretical leakage for each face mask.

Figure 5. Illustration of facemasks included in this study: Surgical mask (A), a covid mask (B), cotton mask (C) and N95 mask (D)

Slika 5. Ilustracija maski za lice uključenih u ovu studiju: kirurška maska (A), maska za covid (B), pamučna maska (C) i N95 maska (D)

RESULTS

The data illustrate the relationship between the face mask air flow rates and the associated differential pressure levels for each of the face masks tested. Table 1 summarizes the results and Fig. 6 illustrates the relationship between mask air velocities and the corresponding dif-ferential pressure levels. This graph shows that the N95 mask (D) imposed the highest re-sistance to air flow while the surgical mask (A) imposed the least resistance. It can be seen that the N95 mask exhibited the highest differential pressure levels that were associated with the lowest mask air flow rates. The surgical mask exhibited the highest air flow rates with the lowest differential pressure. The covid mask and the cotton mask differential pressures and corresponding air flow rates were between these two masks. Table 2 summarizes the air leakage values for the four masks. In comparison, the surgical mask exhibited the lowest leakage while the N95 mask exhibited the highest leakage.

Table 1. Summary of face mask air flow rates and their corresponding differential pressure levels. Air flow decreased when differential pressure increased

Tablica 1. Sažetak protoka zraka maske za lice i odgovarajućih razina diferencijalnog tlaka. Protok zraka se smanjio kada se diferencijalni tlak povećao

Mask Type	Air Flow (L/min)	Differential (Pa)
Control	302.8	0
Surgical (A)	151.2	50
Covid (B)	100.1	66
Cotton (C)	113.2	63
N95 (D)	86.0	70

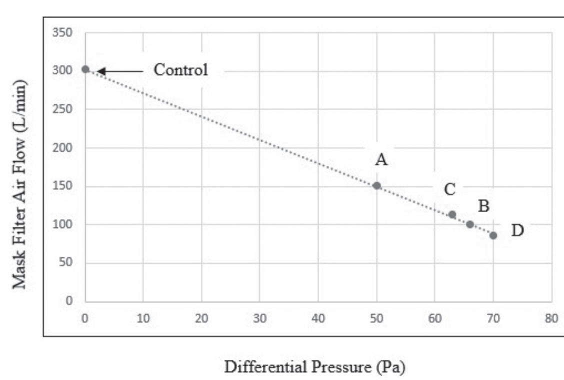

Figure 6. Graphic illustration of the relationship between differential pressure and mask filter air flow for face masks A, B, C and D as summarized in Table 1

Slika 6. Grafički prikaz odnosa između diferencijalnog tlaka i protoka zraka filtra maske za maske za lice A, B, C i D kako je sažeto u Tablici 1

Table 2. Summary of air flow measurements and corresponding peripheral leakage for the four face mask types tested

Tablica 2. Sažetak mjerenja protoka zraka i odgovarajuće periferno propuštanje za četiri ispitane vrste maski za lice

Mask Type	Air Flow (L/min)	Air Flow (%)	Peripheral Leakage (%)
Control	302.8	100	0
Surgical (A)	151.2	50	50
Covid (B)	100.1	33	67
Cotton (C)	113.2	37	63
N95 (D)	86.0	28	72

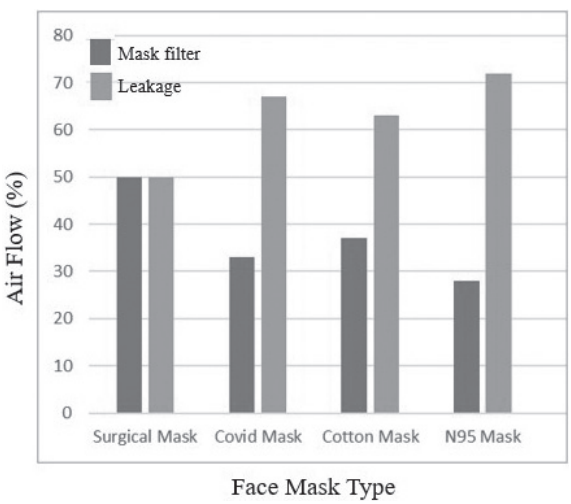

Figure 7. Graphic summary of air flow through the mask filters and their corresponding peripheral leakage

Slika 7. Grafički sažetak protoka zraka kroz filtre maske i njihovu odgovarajuću perifernu propusnost

DISCUSSION

A key factor determining face mask peripheral leakage is the resistance imposed by a mask's filter material. It has been suggested that wearers of high-efficiency masks that have minimal porosity and low air exchange for CO_2 should limit the amount of time the mask is worn *(Salati et al., 2021)*. Therefore, a testing protocol based on the principles of air flow physics, linking face mask leakage to the pressure differentials created by the filter material, can offer relevant health information. The advantage of the new protocol is that face masks will not have to be tested on human subjects or on manekins making the assessment process more effi-cient.

CONCLUSIONS

Face mask leakage always occurs when air bypasses a mask's filter material and enters or exits the mask through gaps between the mask and the face. A wearer creates a negative pressure inside the mask during inhalation and a positive pressure during exhalation. These pressure differentials draw air in, or push air out of the mask that reduce the effectiveness of a face-mask. The results of this study show that all four facemasks tested exhibit relatively high lev-els of peripheral leakage, i.e., above 50%. This information confirms that the effectiveness of face masks currently in use will be limited in protecting against the transmission of airborne pathogens.

LITERATURE

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KVANTITATIVNA PROCJENA PERIFERNOG PROPUŠTANJA MASKI ZA LICE

SAŽETAK: Periferno propuštanje zraka utječe na ulogu maske za lice da štiti nositelja maske od izloženosti zračnim zagađenjima. Propuštanje nastaje kad zrak prolazi izvan materijala filtra i ulazi u masku ili iz maske na mjestima između maske i lica. Nositelj maske stvara negativan pritisak unutar maske pri udisanju i pozitivan pritisak pri izdisanju. Te razlike pritiska uvlače ili tjeraju zrak van iz maske te tako smanjuju njezinu učinkovitost. Osmišljena je zračna komora kojom se jednostavnije procjenjuje prolazak zraka izvan maske. Promjene pritiska i protoka zraka bilježe su pomoću diferencijalnog manometra i digitalnog termoanemometra. Razlike protoka zraka pod maskom i protoka zraka pri otvorenoj konfiguraciji (kontrola) utvrdile su deficit u protoku zraka koji uzrokuje periferno propuštanje zraka. Testirane su četiri različite maske i to kirurška maska, covid maska, pamučna maska i N95 maska. Rezultati su dokazali sličnosti između sva četiri tipa maski. Kirurška maska pokazala je propuštanje od 50 %, covid maska 67 %, a pamučna maska 63 %. N95 maska, pak, pokazala je da je propuštanje 72 %. Rezultate ove studije potvrđuju prethodne studije koje također svjedoče o visokoj razini perifernog propuštanja zraka kod svih maski trenutno u uporabi. Metoda procjene opisana u ovoj studiji nudi novu i jednostavnu metodu za utvrđivanje propuštanja.

Ključne riječi: *maske za lice, periferno propuštanje, pojednostavljena metoda procjene, javno zdravlje*

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