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SYNOPSIS

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Review of "The protective performance of reusable cloth face masks, disposable procedure masks, KN95 masks and N95 respirators: filtration and total inward leakage"

Article citation: Duncan S, Bodurtha P, Naqvi S. The protective performance of reusable cloth face masks, disposable procedure masks, KN95 masks and N95 respirators: filtration and total inward leakage. PLoS ONE. 2021;16(10):e0258191. Available from: https://doi.org/10.1371/journal.pone.0258191

One-minute summary

- The authors investigated aerosol particle penetration and total inward leakage through face masks (i.e., re-usable fabric two-layer masks, re-useable fabric multi-layer masks, disposable procedure/surgical masks, KN95 masks and N95 filtering facepiece respirators [FFR]).
- The authors calculated a mean fabric protection factor (FPF) for each mask, a metric taking into account the penetration of particles and filter efficiency. The higher the mask's FPF, the higher the relative protection. **For each mask type, the authors report geometric mean FPF (geometric standard deviation [GSD]); different superscript letters = significantly different mean FPFs:**
  - **2-layer:** 1.8 (GSD: 1.22)[a]
  - **Multilayer:** 3.6 (GSD: 1.57)[a]
  - **Disposable procedure/surgical:** 9.7 (GSD: 1.17)[b]
  - **KN95:** 145 (GSD: 1.71)[c]
  - **N95 FFR:** 69.8 (GSD: 2.23)[c]
- The combined penetration of aerosol particles (through gaps between the mask and face or through the mask material) was measured as the total inward leakage (TIL) of aerosol particles into the facial cavity of a mask worn by a test subject. The total inward leakage protection factor (TILPF) was calculated as 1/TIL, with higher values representing relatively higher protection. **For each mask type, the authors reported geometric mean TILPF; different superscript letters = significantly different mean TILPFs:**
  - **2-layer:** 1.4 (range: 1.1–2.8)[a]

- **Multilayer:** 1.8 (range: 1.1–4.9)[a]
- **Disposable procedure/surgical:** 2.3 (range: 1.3–8.3)[a]
- **KN95:** 6.2 (range: 3.4–14.7)[b]
- **N95 FFR:** 166 (range: 92.3–319)[c]

- The percent overall penetration of particles was highest for 2-layer masks (≈56%), followed by multi-layer (≈28%), procedure (≈10%), N95 FFR (≈1.4%) and KN95 (≈0.7%).
- Modelling a viral concentration of 0.01% and particle size of 0.3 µm, the percent reduction in viral penetration, compared to a 2-layer mask, was 99.2% for N95 FFRs, 96% for disposable procedure/surgical masks, and 59% for multi-layer masks.
- The median quality factor was highest for KN95 masks (≈0.095 Pa^{-1}), followed by disposable procedure/surgical masks (≈0.07 Pa^{-1}), multi-layer masks (≈0.035 Pa^{-1}) and 2-layer masks (≈0.01 Pa^{-1}). Note that the median quality factor was not presented for N95 FFRs due to dissimilar face velocities compared to the other mask types.
- The authors concluded that N95 FFRs were the only masks investigated that provided both high FPF and TILPF. Further, N95 FFRs are the best option to protect individuals from exposure to aerosols in high-risk settings. In addition, mask fit with an effective face seal is more important to increasing TILPF than the mask material.

Additional information

- **Percent aerosol penetration:** Aerosol penetration through masks was tested using an aerosol swatch (mask material) penetration set-up (please see paper for details and schematic). The authors used a polydisperse (≈0.023–5 µm) sodium chloride (45,000–60,000 particles/cm^3) aerosol to challenge each mask fabric, with aerosols generated in the mixing chamber and pulled through a neutralizer and swatch test rig using a regenerative blower. Air flow was regulated using a flow meter and the aerosol concentration (upstream and downstream) was measured with the scanning mobility particle sizer (SMPS)/aerodynamic particle sizer (APS) (performed up to 4 times per mask). To simulate expiration of a person at rest, the authors tested masks at a flow rate of 17 L/min. Aerosol penetration through a mask was calculated by measuring the aerosol concentration upstream and downstream from the mask material, where % penetration = 1 – filtration efficiency (see paper for further details, formula and calculations). Masks of different brands and materials were tested within each group: 1) 2-layer (n=5 types); 2) multi-layer (n=10); 3) disposable procedure/surgical (n=6); 4) KN95 (n=2); and 5) N95 FFR (n=5).
    - **The percent maximum penetration of particles (occurring at maximum penetrating particle size) through each mask type:**
        - **2-layer:** 91.9% (0.81 µm)
        - **Multilayer:** 45.2% (0.37 µm)
        - **Disposable procedure/surgical:** 26.4% (0.058 µm)

- **KN95:** 2.3% (0.12 µm)
- **N95 FFR:** 3.4% (0.076 µm)

- **Fabric protection factor (FPF):** The FPF was calculated by taking the reciprocal of the mean number penetration for each particle diameter in the distribution, then converting this value to a protection factor and then calculating a harmonic mean FPF (please see paper for formula). Per authors, the FPF metric is routinely used by the United States Occupational Safety and Health Administration (US OSHA), National Institute for Occupational Safety and Health (NIOSH) and the Canadian Standards Association (CSA) for calculating overall protection and fit in respiratory protection standards.

- **Total inward leakage (TIL) and total inward leakage protection factor (TILPF):** TIL is used to estimate the overall performance of a face mask under laboratory conditions. Aerosol generation, particle size and concentration was the same as the penetration swatch test. The authors did not provide details on the volunteers, but were selected from Defence Research and Development Canada employees and were trained in proper usage of masks and fit-tested for N95 FFRs. The authors selected 11 volunteers to approximate a cross-section in terms of sex, age, height, weight and face size. The TIL test involved seven activities involving head/face/body movements for a duration of 30 seconds each. Aerosols outside of the mask were sampled 10 cm away from the participants' face. Masks of different brands and materials were tested within each group: 1) 2-layer (n=4 types); 2) multi-layer (n=4); 3) disposable procedure/surgical (n=2); 4) KN95 (n=2); and 5) N95 FFR (n=1).

PHO reviewer's comments

- This study quantified filtration efficiency and total inward leakage of a variety of mask types used during the COVID-19 pandemic, demonstrating substantial variation based on the materials used.

- Disposable procedure/surgical masks had a higher level of protection against particle penetration than 2-layer or multi-layer masks, and KN95 and N95 FFR had the highest filtering performance. Although KN95 models had filtering performance comparable to N95 FFRs, total inward leakage was much lower than N95 FFRs, highlighting the importance of an effective seal to the face for reducing total inward leakage and protection of the wearer. However, the TILPF for the KN95s tested were still appreciably higher than the 2-layer, multi-layer or disposable procedure/surgical masks tested.

- The addition of filter layers to 2-layer masks reduced average particle penetration to some degree. However, the third filtering layer was not always beneficial, and depended on the type of fabric.

- All mask types provided some total inward leakage protection and reduced concentration of aerosols downstream. Inward leakage protection can serve as a proxy measure for source control.

- The authors tried to account for some 'real world' factors, such as recruiting volunteers with a variety of facial structures and using test air flow rates to mimic typical breathing. Still, as an experimental study, many factors that influence mask/respirator use and adherence in real-world settings would not have been replicated, limiting generalizability. However, the results

overall are consistent with previous studies that have demonstrated the importance of fit as well as filtration, and the wide variation in filtration efficiencies of commonly available fabrics. Although not discussed explicitly in the paper, comfort and breathability are also important aspects to consider in places or contexts where indoor masking mandates are in effect.

- It is important to consider the purpose and setting for mask use when selecting the most appropriate type (i.e. source control vs. personal protective equipment). Mask use in community settings is primarily for source control to reduce the risk to others, and part of a multi-layer suite of prevention measures. Masks for personal protection are used in healthcare and other occupational settings. Training, and when appropriate fit-testing, are important components for optimizing personal protective equipment. The high protection level observed for N95 FFR depends heavily on good fit; hence, wearers need to be fit-tested to find a model that suits their face shape and ensure a seal each time it is used.

- Within the suite of masks tested, it was unclear if any were designed for the pediatric population. With this in mind, a similar analysis for masks designed for children would be helpful for possible application in the school setting.

- In addition, the study did not explore if the FPF and TILPF may drop after prolonged use of the masks/respirators (and re-use for the fabric masks), as some masks may become less effective over time, e.g., during a typical day of use.

Citation

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