Surgical mask covering of N95 filtering facepiece respirators: The risk of increased leakage

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In this report, we demonstrate the potential risk of increased face-to-mask seal leakage when N95 filtering facepiece respirators (N95 FFRs) are covered by surgical, cloth, or medical masks, (collectively referred to as surgical masks), through analytical modeling of the associated fluid mechanics and seal pressures. Previously published experimental studies of respirator pressures and leakage are applicable to this problem. Properly utilized N95 FFRs will remain an essential component of healthcare worker safety for the foreseeable future, especially for those engaged in aerosol-generating procedures (AGPs) such as endotracheal intubation.[1–3] When considering leakage risk, it is important to understand the general challenges to ensuring an adequate mask-to-face seal. The fit and seal degrade with repeated donning and doffing, and some N95 FFR reprocessing or recycling techniques have been reported to accelerate this degradation.[4] In short, the N95 mask-to-face seal is fragile and can be compromised by a number of factors.

Methods

The surgical mask creates additional resistance to airflow compared to only an N95 FFR. As a porous medium, the ease of movement of the fluid through the N95 can be modeled as permeability "k" in Darcy's law.[5] Darcy's law states that the flow rate through the porous medium is proportional to the permeability and the pressure drop across this medium:

$$Q = \frac{-kA}{\mu L}\Delta p \tag{1}$$

where Q is the volumetric flow rate (analogous to minute ventilation), A is the cross-sectional area, μ is fluid viscosity, L is the length of the porous medium, and Δp is the pressure drop.[5,6] This law states that for the same amount of pressure drop, the flow rate permeating the porous medium decreases as the length of the medium increases. According to Eq. (1), if a surgical mask is being used to cover a N95 FFR, the length of the porous medium (ie, thickness of both masks) is increased and therefore a lower air flow rate penetrates through the masks for the same pressure drop across the masks. To maintain a normal minute ventilation, the breathing pressure (pressure drop, Δp) must therefore increase as the resistance increases.

Considering Eq. (1), if Q_B is the normal volumetric flow rate passing through a mask, then the pressure drop across this mask is defined as follows:

$$\Delta p = \frac{-Q_B\mu}{A}\frac{L}{k} = -Q_B\mu\ R \tag{2}$$

where R is defined as flow resistance ($\frac{L}{kA}$), analogous to a resistor in conduction of electricity.[7]

For multiple masks (ie, a surgical mask over a N95 FFR), the total pressure drop across the masks is equal to the sum of the pressure drop across each mask individually.

Therefore, the total pressure drop can be defined as follows:

$$\begin{aligned}\Delta p_{tot} &= -Q_B\mu\ R_{eq}\\ &= -Q_B\mu\ \sum\nolimits_{icomma=1}^{2} R_i = -Q_B\mu comma(R_1 + R_2)\end{aligned} \tag{3}$$

where R_{eq} is the equivalent flow resistance of the 2 masks and R_1 and R_2 are the flow resistances for the N95 FFR and the surgical mask, respectively. Equivalent flow resistance is calculated by the summation of resistances, similar to resistors in series in an electrical circuit.[7] From Eq. (3), because the breathing flow rate is unchanged and the flow resistance has increased by the amount of R_2, the total pressure drop across the 2 masks increases as compared to only using an N95 FFR. This additional resistance from the addition of the surgical mask, in turn, creates increased breathing pressures within the mask and airway relative to atmospheric (room air) pressure when the user maintains normal minute ventilation.

Thus, the respiratory cycle pressures will necessarily be more negative on inspiration and more positive on expiration to overcome the increased resistance of the combined masks in an attempt to maintain normal airflow or minute ventilation. As the pressure drop increases across the masks, the same atmospheric-to-airway pressure drop applies to the N95 FFR edge-to-face seal. As a result, as higher pressure differentials pulsate across a pliable mechanical seal, such as the N95 FFR edge-to-face seal, leakage can incrementally occur.

When the face and N95 FFR edge meet to form a seal, any separation between the mating surfaces increases leakage substantially. Doubling seal-surface separation can increase leakage by a factor of 8.[8] This is shown by approximating the critical constriction at a seal interface as a pore with a rectangular cross section with a long width and relatively small height. Assuming incompressible Newtonian fluid, and u_1 as the average height separating the mating surfaces, the volume flow per unit time, Q_l (leakage flow rate), through the critical constriction is given by the following equation (Poiseuille flow):

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$$Q_l \propto \frac{u_1^3}{\eta} \Delta p \tag{4}$$

where η is the fluid viscosity, and Δp is the pressure differential across the masks as shown in Eq. (3).[8]

Results

The increased pulsating pressure differential created by an overlying surgical mask potentially causes increased leakage according to Eq. (4).[8,9]

Discussion

The analytical model includes simplifying assumptions such as negligible effects of multiphase flow and leakage around the surgical mask edges. In addition, the seal's balance ratio might increase during inhalation, thereby creating a countering increase in seal competence.

Covering N95 FFRs with a surgical mask can potentially increase the occurrence of N95 FFR leakage. Appropriate assessment of this risk will require additional research, including higher-order theoretical analysis, computational fluid dynamics modeling, bench tests, and/or human studies. As we engage in that work, we encourage others to do the same. Pending further study, N95 FFR clinical guidance and instructions to cover N95 FFRs with surgical masks should consider and assess this risk.

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Use and perceptions of antibiotics among US adults aged 50–80 years

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Although antibiotics can be life-saving agents, inappropriate use contributes to antibiotic resistance and drug-related adverse effects.[1,2] The University of Michigan National Poll on Healthy Aging (NPHA) is a nationally representative survey of adults aged 50−80 years that surveys participants in Ipsos KnowledgePanel (Ipsos Public Affairs, Washington, DC). This survey was fielded in May 2019. The University of Michigan Institutional Review Board deemed this study exempt from review.

Along with demographics and self-reported health status, respondents were asked several questions about personal use of oral antibiotics during the previous 2 years. The survey completion rate was 76%. The margin of error was ±1%–2% for questions asked of the full sample, and it was higher among subgroups. Analyses used poststratification weights to draw national inferences and were performed using Stata version 15.1 software (StataCorp, College Station, TX). A 2-tailed P <0.05 was considered statistically significant. The weighted proportion of respondents for each covariate, stratified by use of antibiotics in the previous 2 years, was calculated, and χ^2 tests were performed.

Among 2,256 respondents aged 50–80 years, 47.7 % (95% confidence interval [CI], 45.5–49.9) reported an antibiotic prescription in the previous 2 years. The most common indications included respiratory (49.7%), dental (17.6%), urinary tract (16.6%) and skin (11.7%) infections. Among those who filled a prescription, 139 of 1,091 (12.7%; 95% CI, 10.7%–14.9%]) had leftover medication, with similar percentages among younger and older respondents. The top reasons for having leftover antibiotics included the following: given more doses than needed (33.5%), stopped because they felt better (32.4%), stopped due to side effects (18.2%), forgot or skipped doses (14.4%), and stopped taking because it did not help (7.0%).

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