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Particle Release from Respirators, Part II: Determination of the Effect of Tension Applied in Simulation of Removal

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This study evaluated the potential for disposable filtering facepiece respirators (hereafter termed masks) contaminated with 1-μm particles to release particles as a result of lateral tension applied to the mask. The lateral tension was designed to simulate the removal of a contaminated mask from a user's head. Four brands of filtering facepieces were loaded with approximately 20 million 1.0-μm polystyrene latex (PSL) microspheres. The respirators were then placed in a test chamber and subjected to lateral tension between 17.8–26.7 N (4–6 lbs) for 1 to 2 sec. The findings suggest that neither mask type nor loading condition affects particle release. This supports our hypothesis that when filtering facepiece respirators are properly removed from the head they will not release a significant number of particles.

Keywords particles, release, removal, respirator, stretch

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INTRODUCTION

This is a continuation of a previous study(1) also in this issue. The data presented in Part I show that particles can be released when a contaminated respirator is dropped. This study was conducted to investigate if there are other realistic use situations that would lead to the release of particles from filtering facepiece respirators. The act of removing a respirator from the head, which requires stretching and flexing of the device, was selected as another handling scenario that may result in the release of particles. If particles are released to any great extent as a result of the respirator removal process, handling and use procedures may need to be modified in high hazard situations. A negative outcome determining that particles are not released during the removal act would also be useful information. This study was designed to simulate the removal of contaminated filtering facepieces from one's face by applying a lateral tension to the mask near the point of strap attachment.

PREVIOUS WORK

Kennedy et al.(2) attempted to characterize the fractional release of particles from filtering facepiece respirators when dropped onto a hard surface. They found that 1-μm polystyrene latex (PSL) spheres are released from filtering facepieces when dropped from a height of 3 ft onto a rigid surface. Part I(1) provides more detailed information on particle release when respirators are dropped. There is no published literature on particle release from filtering facepiece respirators as a result of tension applied to the respirator in a simulation of the stress on a facepiece while removing it.

EXPERIMENTAL

Each test consisted of three phases: (1) particle loading, (2) mask stretching, and (3) particle counting using a model 3310 aerosol particle sizer (APS; TSI Inc., Shoreview, Minn.). Four brands of N95 filtering facepiece respirators were tested. For each test run, a new respirator was first loaded with approximately 20 million 1-μm PSL spheres. The particle size chosen is based on the fact that many bacteria and viruses are in the size range. The 20-million particle load was chosen as this loading level could be performed within a reasonable timeframe. The loading chamber as well as other components of the test apparatus are described in Part I.(1) The APS was used to measure the average number concentration in the loading chamber, which allowed real-time calculation of the sample volume required to reach the target loading condition. Variations in load were accounted for by using the actual load number instead of the target load level when determining fractional particle release.

After loading, each mask was carefully removed from the load chamber. Clamps attached to rods were placed on either side of the mask in approximately the center of the area where

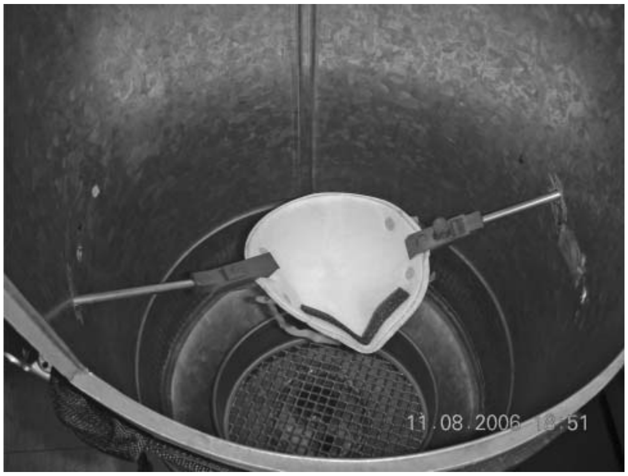

FIGURE 1. Clamped mask configuration.

straps are attached to each respective mask (Figure 1). It was assumed that attaching these clamps and the handling of the masks did not cause significant particle release. Whether this is a correct assumption needs to be investigated further, but the authors had no reasonable means to test this with this experimental setup.

The masks were then placed inside a test chamber with the rods protruding through small holes. The chamber was allowed to clear, and then each mask was subjected to a stretch force for 1 to 2 sec and then quickly released. A representative series of stretches was conducted for each respirator and tension was measured using a Digital Force Gauge Model MG100L (MARK-10 Corp., Copiague, N.Y.). Based on actual donning and doffing of these types of respirators, it was determined that 17.8–26.7 N (4–6 lbs) of tension was being placed on the respirators. This range could easily be repeated for the tests. Each loaded mask with approximately 20 million particles was stretched at the prescribed tension and time; the particles released from the mask were sampled under isokinetic conditions and counted using the APS as described in Part I.

A spreadsheet was used to mathematically adjust the counts for the effects of bypass exhaust and hose losses. This adjustment is explained in detail in Part I. Particle release per 10,000 particles loaded was then calculated. The drop chamber was washed after each sample run. The order of respirators tested for each sample was randomized. Each brand of mask was tested 30 times under the same set of experimental conditions. Ten blanks were tested for each model of respirator. Blanks were respirators treated in the same manner as each test sample without being loaded (unloaded) with PSLs. Blanks therefore provided an estimate of the release of extraneous particles and inherent dust associated with the unloaded respirator. A total of 160 data points were obtained for this study.

ANALYSIS

Linear regression analysis on the square root of particle release was conducted. We sought a transformation that would normalize outcomes and thereby make normal-based statistical tests such as the F-test more valid, while retaining a strictly positive outcome. This was the basis for the square root transformation. Three experimental factors were included in the model to investigate their relation to particle release: mask type, load condition, and stretch condition. Mask type was a categorical variable with four groups, while the load and stretch factors were both dichotomous. All main and interactive effects were included as covariates. Standard F tests were used to determine the significance of the estimated regression coefficients of the multivariate regression. All analyses were performed using STATA Intercooled 9.1 (Stata Corp. LP, College Station, Texas) data analysis and management software.

RESULTS

The outcome measure of interest was proportionate particle release, which is the number of particles released per 10,000 loaded particles. Release was measured under loaded and unloaded conditions (blanks) for each of the four mask types studied. A blank mask is a mask in an unloaded condition yet stretched and measured for extraneous release of dust particles that needed to be accounted for when loaded masks were stretched. In each experiment, a stretch and relaxation was applied to the mask and particle release was counted. The size of the particles that were used was 1 μm. A few extreme values were observed. For this reason the square-root of the particle release was used in comparing the mean proportionate release by mask type. Graphical analysis (Figure 2) suggests comparable means under the loaded and unloaded conditions, though there was greater variability

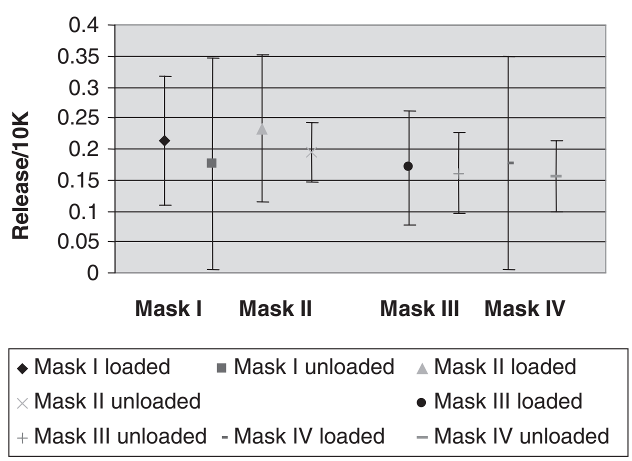

FIGURE 2. Particle release loaded vs. unloaded.

for the loaded condition. Regression analysis was used to test the effect of mask type. We considered all second-order interactive effects but, as none were found to be significant, we report estimates for the model with only main effects.

The data were found to slightly deviate from normality and had several outlier data points. To eliminate the influence of two extreme values observed in the analysis, the consistency of the reported results was assessed by removing these two observations from the sample and performing the same set of analyses. There was no change in the conclusion. Results of this study are robust despite the slight deviance from normality among the residuals in the complete data set. Because the number of particles released on loaded masks was very small, there were situations where unloaded masks released a greater number of particles from the extraneous and inherent dust particles naturally associated with them.

When looking at the data for the entire set of test runs, there is no effect of the load condition (p-value = 0.62), meaning that release from the loaded respirators was not different from release from the blanks. Masks I and II did exhibit a higher mean release (p-value = 0.001), which was not unexpected based on the results reported in Part I. Thus, the evidence generally indicates that when a stretch is applied, particle release for these mask loaded with 1-μm PSL spheres is negligible when compared with the dropping of loaded masks under certain conditions as discussed in Part I. For example, in Part I, release of 1-μm PSL spheres for masks dropped from 1.37 m ranged from 0.48 to 4.38 particles per 10,000 particles loaded on masks.

DISCUSSION

For all respirators tested, there was no significant difference in particle release when comparing each respective mask type to its blank; therefore, it appears that if our study adequately simulated mask removal, then the act of removing a used mask from one's head does not cause particles to be released. This is an important finding in that this alleviates some concern in reaerosolization of particles when a mask is removed. If the act of removing a mask from one's head causes the release of particles this would be of concern to the user as well as to those around the user. The risks associated with particle release, if it occurred as a result of the removal process, might differ depending if the contaminant is an industrial contaminant having exposure limits or a microorganism having no exposure limits. In addition, different mask construction and the inherent differences in adhesion properties of the masks may have a significant effect of particle release from mask removal.

Removal of a respirator is an unavoidable and necessary action. If significant numbers of particles were released as a result of this act, it would require different and possibly onerous removal procedures, depending on the type of hazard. If evidence indicated that stretching of the mask during removal should be avoided, then cutting of the straps, removal in an area upstream of airflow, or other removal techniques might be required. Also, if particles were released from masks during removal there might be greater concern for hand to mucosa contamination. When masks are used in a health care setting, procedure requires that used masks be removed by a gloved hand, with the gloves subsequently removed and discarded.

The predominant information that can be gained from this study is that under usual handling conditions when removing a filtering facepiece respirator from the head there appears to be negligible particle release of the contaminant. Other more severe conditions can result in a significant amount of particle release.[1]

CONCLUSION

Although the dropping of filtering facepiece respirators onto a hard surface causes the release of particles from them,[1] there appears to be no significant release as a result of removing these types of respirators from the head.

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