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# Storage and Availability of Elastomeric Respirators in Health Care

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Use of reusable respirators, such as elastomeric half-face respirators (EHFRs), may serve as one solution to combating the problem of N95 respirator shortages experienced during infectious disease emergencies. To clarify whether logistical issues like respirator storage and availability are barriers to implementation of healthcare respiratory protection strategies that include EHFRs, this study aimed to evaluate the availability, storage, and respirator and filter replacement practices of EHFRs used in healthcare settings under routine use. Healthcare workers using EHFRs were surveyed about their use practices. To explore whether issues related to storage and availability of EHFRs affected compliance with assigned respirator use, responses were compared between concordant users and EHFR users who were assigned to use EHFRs but currently use different respirators ("discordant users"). Most concordant EHFR users reported that their respirator was always available when needed (63.8%). Almost two-thirds of concordant but only half of discordant users reported storing their EHFRs conveniently in the patient care area ($p = <0.001$). Among mobile workers, discordant users had higher odds (aOR = 3.2, 95% CI [1.4,7.5]) of reporting that their respirator was not stored in the patient care area, suggesting that storage location has a significant impact on compliance with expected practice, particularly in this group. Storage and access are barriers to optimal elastomeric respirator use in healthcare. Strategies to assure ready availability and storage of respirators will permit EHFR inclusion in pandemic and routine respiratory protection programs.

**Keywords:** Hospital preparedness/response, Influenza, Personal protective equipment

Protecting healthcare workers from airborne hazards often requires the use of respiratory protection. Conventionally, disposable N95 filtering facepiece respirators have been used to meet this need.[1,2] All major respiratory pandemic threats over the past 20 years have required use of respiratory protection, leading in each event to N95 shortages.[3,4] Preparedness strategies for future infectious disease outbreaks must include provisions addressing anticipated shortages of disposable N95s.

One solution to anticipated shortages of disposable N95s may be inclusion of reusable elastomeric respirators as part of a hospital's respiratory protection program. These

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devices, while commonly used outside of healthcare, are often unfamiliar to most healthcare workers and hospital respiratory protection program administrators.[5] Potential advantages of these devices include the ability to clean, disinfect, and use them repeatedly and their ready availability for purchase in advance of need. While initial questions about elastomeric respirator use have focused on user acceptability, respiratory protection program decision makers have also raised questions about logistical issues that could impede practical use in healthcare settings.[6,7] Respirator availability, storage, and replacement practices could all be barriers to use of such a device in a healthcare setting.[6,7]

The National Academies of Sciences, Engineering, and Medicine have indicated that elastomeric respirator use is a viable option for routine and surge use in healthcare settings, provided that storage strategies have been planned.[7] In the United States, the Occupational Safety and Health Administration's (OSHA) respiratory protection standard requires that employers provide for the storage of respirators used by their employees and specifies that employers must ensure accessibility to respirators. It requires that respirators be protected from damage, contaminants, dust, sunlight, extremes of temperature, moisture, and chemicals, and that they be stored in a way to prevent deformation and in accordance with manufacturer instructions.[8] With respect to filter change-out schedule, traditionally filters are recommended to be changed when the expiration date has been reached, when work of breathing becomes increased, or when the filters become visibly soiled or damaged. Respiratory protection program practices related to device availability, storage, and filter change for healthcare environments have largely been extrapolated from general industry environments. In general industry, where elastomeric respirators have found most of their use, well-maintained devices have sustained years of repeated use.[7,9,10]

While elastomeric respirators are not typically found in healthcare settings, some limited reports of their use have been described.[2,6,11,12] One hospital setting with more than 5,000 employees enrolled in its respiratory protection program has used elastomeric half-face respirators (EHFRs) as a form of respiratory protection since the H1N1 2009 pandemic.[6] In the fall of 2016, healthcare workers from this facility and its affiliated institutions were surveyed about their experiences with respirator use. The survey focused particularly on availability of EHFRs at point of use, where and how they store their respirators, and frequency and need for replacement of masks and filters.

The primary objective of this study was to understand the logistical issues related to point-of-use availability, short-term storage, and respirator and filter replacement associated with routine use of EHFRs in healthcare settings. To do this, EHFR users were surveyed about their use practices. Healthcare workers who were assigned and currently using EHFRs ("concordant users") and healthcare workers who were assigned to use EHFRs but were unofficially (and autonomously) currently using a different respirator ("discordant users") were surveyed. This latter group engaged in practices that were incongruent with expected respiratory protection protocols. Observing this behavior, a secondary objective was then to determine if device availability, storage, and respirator and filter replacement contributed significantly to compliance with expected use practices. If so, then these aspects would be critical determinants in examining EHFRs as a feasible solution to addressing N95 shortages during pandemic emergencies.

## Methods

### *Setting*

Healthcare workers were surveyed who were enrolled in respiratory protection programs at 5 healthcare sites within a single medical system. Collectively, 3 different forms of respiratory protection were in use across the participating sites: N95s, EHFRs, and powered air-purifying respirators (PAPRs). Elastomeric half-face respirators were used in 2 of the 5 sites: (1) a large, urban academic medical center, and (2) its associated ambulatory practices. Data included for this analysis were derived solely from healthcare workers who currently or previously reported using EHFRs. The study was approved by the local university institutional review board.

### *Survey Design, Development, and Deployment*

The survey was informed by feedback provided by healthcare workers who were familiar with use of EHFRs and who participated in a previous focus group about respiratory protection.[6] The respiratory protection program leadership involved with implementation and management of the elastomeric respirator-based respiratory protection programs also provided insight during key informant interviews.[6] Questions specifically focused on storage, availability, and replacement of EHFRs were asked only to participants who reported wearing EHFRs and not to healthcare workers who reported wearing N95s or PAPRs.

An online survey consultant hosted and administered the survey, which was structured to take 15 to 20 minutes to complete. It was able to be completed in intervals, and in multiple browser options, both on desktop and mobile electronic options. The study team obtained rosters and available email addresses of all healthcare workers involved in the respiratory protection programs. The online survey consultant delivered individual emails to all healthcare workers listed on the rosters; these included an introductory email, the invitation email containing a personalized link to the survey, and up to 3 reminder emails over a 6-week period to those participants who had not completed the survey.

The survey was administered between August and October 2016. Because some healthcare workers did not have email addresses on file with employee health rosters, study staff also scheduled clinical unit visits with study-supplied laptops where participants could complete the survey on site. Clinical units that historically had been designated as elastomeric units were prioritized (ie, emergency department, medical intensive care unit, medicine and pediatric units, respiratory therapy, radiology and phlebotomy units). Participants were eligible to complete the survey if they were assigned to wear a respirator, were at least 18 years old, had worked for their current employer for at least 3 months, and had worn a respirator at least once outside of training in the past year. A total of 2,024 EHFR-users were estimated to be eligible to participate at the time of survey deployment based on employee health rosters. Additional details about setting and survey methods related to different research questions among the same population have been described previously.[13]

## *Analysis*

The sample analyzed consisted of responses from healthcare workers who had been assigned to use an EHFR respirator, including those who were and were not currently using their EHFR respirator as their primary mode of respiratory protection. To assess potential discrepancies between actual and assigned respirator use, we asked participants to report what respirator they most recently had been assigned to use, and then asked what respirator they usually use. These user groups were then classified as either concordant EHFR users or as those assigned to use EHFRs but who usually use something different, or discordant users. Chi-square tests were used to compare the 2 user groups on dichotomous and other categorical demographic and background characteristic variables. A Wilcoxon rank-sum test was used to compare the user groups by the number of years worked in healthcare.

Frequency distributions for the entire sample of EHFR users were calculated to address the primary study objective of understanding respirator availability and storage practices as reported by all elastomeric users. To address the secondary objective of understanding whether concordant EHFR users and discordant users reported different practices, frequency distributions of responses were compared between these 2 user groups using Chi-square analysis. Differences between concordant EHFR users and discordant users were then reevaluated after adjusting for factors thought to potentially affect these responses that were significantly different between the 2 user groups using a separate multinomial logistic regression model for each response variable. Odds ratios were calculated for reporting of specific practices in discordant compared to concordant EHFR users, adjusted for job category, site (ie, urban academic hospital; urban ambulatory practice; urban, suburban, or rural community hospital), primary unit (ie, medical floor, surgical floor, intensive care unit, etc), frequency of respirator training/fit-testing, and years worked in healthcare.

To prevent regression model overfitting in the multivariable analyses, noncritical categories of outcomes and independent variables were folded into larger or more meaningful categories (ie, collapsed). For example, to test the hypothesis that mobile workers such as doctors and respiratory therapists might report different practices compared to healthcare workers who work in more fixed locations, responses of providers and respiratory therapists were grouped together for adjusted analysis and compared to nurses.

A post hoc analysis was performed to explore the possibility that differences between discordant and concordant EHFR users were modified depending on job category and frequency of respirator training/fit-testing (effect modification). This analysis was conducted by adding interaction terms between user status and the above 2 independent variables. Stratified odds ratios were calculated for the outcome measures found to be significantly different between concordant and discordant users in the earlier analyses. All analyses were conducted using SAS version 9.4 (SAS Institute Inc., Cary, NC).

## Results

Approximately 21% of EHFR users completed the survey. Out of 432 healthcare workers who reported using elastomeric respirators, 280 (65%) were concordant users of EHFRs, and 142 (35%) were discordant users. Demographic and occupational characteristics of the groups are shown in Table 1.

Most concordant EHFR users reported that their respirator was always available when needed (Table 2). In contrast, more discordant users reported that their respirator was "usually" available or available even less often. When asked specifically about storage location, concordant EHFR users differed significantly from discordant users: Almost two-thirds of concordant users but only half of discordant users reported storing their EHFR conveniently nearby in the patient care area (Table 2). There were no significant differences between respirator user groups in method of storage (Table 2).

Most EHFR users had never changed the filters on their masks, but more concordant EHFR users reported doing so than did discordant users (Table 3). An even greater number had never obtained a replacement respirator (Table 3), with more of the discordant users reporting doing so because of loss or theft of their respirator. This was not significantly different, however, compared to concordant users.

Use practices between discordant and concordant EHFR users were then compared and adjusted for co-variates as shown in Table 4. Discordant EHFR users differed from concordant users in reporting that their respirators were not always available and that they had never changed their

Table 1. Demographic Characteristics of Concordant Compared to Discordant EHFR Users ($n=432$)

| | *Concordant EHFR Users* | | *Discordant EHFR Users* | | |
|---|---|---|---|---|---|
| | n = *280* | *65%* | n = *152* | *35%* | |
| | *n* | *%* | *n* | *%* | *p-Value* |
| Female gender | 239 | 85 | 129 | 85 | 0.891 |
| Age | | | | | 0.347 |
| <30 | 93 | 33.2 | 39 | 25.7 | |
| 30 to <40 | 91 | 32.5 | 56 | 36.8 | |
| 40 to <50 | 45 | 16.0 | 23 | 15.1 | |
| 50+ | 51 | 18.0 | 34 | 22.4 | |
| Race | | | | | 0.893 |
| Nonwhite | 105 | 37.5 | 58 | 38.2 | |
| White | 175 | 62.5 | 94 | 61.8 | |
| Education | | | | | **0.004** |
| Doctoral degree | 22 | 7.9 | 30 | 19.7 | |
| Master's/some post-bachelor's | 48 | 17.1 | 29 | 19.1 | |
| Bachelor's degree | 113 | 40.4 | 53 | 34.9 | |
| Some college | 67 | 23.9 | 31 | 20.4 | |
| High/tradeschool/other | 30 | 10.7 | 9 | 5.9 | |
| Job Type | | | | | **<0.001** |
| Nurse (non-mobile) | 131 | 46.8 | 59 | 38.8 | |
| Patient support/other[a] (non-mobile) | 105 | 37.5 | 34 | 22.4 | |
| Mobile workers | 44 | 15.7 | 59 | 38.8 | |
| RT | 20 | 7.1 | 23 | 15.1 | |
| Provider | 24 | 8.6 | 36 | 23.7 | |
| Primary Unit Setting | | | | | **<0.001** |
| Higher risk inpatient units | 186 | 66.4 | 96 | 63.2 | |
| Lower risk inpatient units | 30 | 10.7 | 35 | 23.0 | |
| Ambulatory/lab/radiology | 64 | 22.9 | 21 | 13.8 | |
| Site | | | | | **0.011** |
| Urban academic hospital | 226 | 80.7 | 137 | 90.1 | |
| Urban ambulatory/other[b] | 54 | 19.3 | 15 | 9.9 | |
| Percentage of time wearing a respirator | | | | | 0.931 |
| 0-1% | 124 | 44.3 | 67 | 44.1 | |
| 1-10% | 99 | 35.4 | 56 | 36.8 | |
| >10-25% | 57 | 20.4 | 29 | 19.1 | |
| Frequency of training/fit-testing | | | | | 0.052 |
| At hire and annually | 214 | 76.4 | 103 | 67.8 | |
| Other | 66 | 23.6 | 49 | 32.2 | |
| Wore a respirator during 2009 H1N1 | | | | | 0.067 |
| Yes | 93 | 33.2 | 64 | 42.1 | |
| No | 187 | 66.8 | 88 | 57.9 | |
| | | *mean years (SD)* | | | |
| Years worked in healthcare | 12.0 | (10.0) | 13.6 | (10.0) | **0.028** |

[a]Includes patient care technicians, medical and nursing assistants, and all other roles.
[b]Largely composed of urban ambulatory site, but <10 from urban community, suburban community, suburban/rural community sites also included.
*Notes.* EHFR = elastomeric half-face respirator; RT = respiratory therapist
RTs grouped with providers for adjusted analysis; significant difference in distribution of job categories between current and discordant users was unchanged once these 2 categories were collapsed into 1 ($p<0.0001$).

respirator filters. They were not different from concordant EHFR users overall with respect to reporting of storage location or storage technique and in frequency of obtaining replacement respirators.

To explore the impact of training frequency and work organizational factors outcomes related to storage and availability, interactions of job category and frequency of training/fit-testing with noncompliant status on the outcomes found to be significant during the earlier frequency analyses: availability, storage location, and filter change frequency. Among the 3 job categories, discordant users were consistently more likely than concordant users to report that their respirator

Table 2. Elastomeric Respirator Availability and Storage Location/Technique Reported by Concordant Compared to Discordant EHFR Users ($n=432$)

| | *Concordant EHFR Users* | | *Discordant EHFR Users* | | |
|---|---|---|---|---|---|
| | n = *280* | *% of Group* | n = *152* | *% of Group* | *p-Value* |
| *Is the respirator model and size you were assigned available when you need it?*[a] | | | | | **<0.001** |
| Half the time or less | 12 | 4.4 | 30 | 19.7 | |
| Usually | 53 | 19.2 | 60 | 39.5 | |
| Always[b] | 211 | 76.5 | 62 | 40.8 | |
| *When my reusable elastomeric respirator is not in use, I store it:* | | | | | **<0.001** |
| Patient care area[c] | 183 | 65.4 | 80 | 52.6 | |
| Somewhere on campus | 26 | 9.3 | 17 | 11.2 | |
| Other | 54 | 19.3 | 17 | 11.2 | |
| In car, at home, or don't know | 17 | 6.1 | 38 | 25.0 | |
| *My reusable elastomeric respirator is stored:* | | | | | 0.296 |
| In a sealed plastic bag so that it retains its shape | 162 | 57.9 | 80 | 52.6 | |
| Other | 118 | 42.1 | 72 | 47.4 | |

[a]Four current EHFR users did not answer this question; percents expressed in relation to percent answering question.
[b]For subsequent analysis of respirator availability, responses were collapsed into "always" versus all other responses (ie, "usually" combined with "half the time or less").
[c]For subsequent analysis of respirator storage location, responses were collapsed into "patient care area" versus all other responses combined.
*Note.* EHFR = elastomeric half-face respirator



was not always available, and there was no significant change in this association when job category was accounted for.

When storage location was evaluated among nurses and patient support or other workers, discordant users did not differ from concordant users regarding the odds that they stored their EHFR respirator away from a patient area; however, among the mobile workers, discordant users did have a significantly higher odds ratio than concordant EHFR users (aOR = 3.2, 95% CI [1.4,7.5]) of reporting that their respirator was not stored in the patient care area. Among mobile workers (aOR = 3.4, 95% CI [1.4,8.3]) and nurses (aOR = 5.03, 95% CI [1.6,15.8]), discordant users were more likely to report that they had never replaced the filters in their respirator; however, among patient and other support staff, discordant users did not differ in the likelihood that they had replaced the filters in their respirator. Frequency of fit-testing/training did not significantly alter the association between discordant user status and reported availability, storage location, or filter change frequency.

## Discussion

### *Summary of Findings*

This study sought to understand the logistical issues related to point-of-use availability, short-term storage, and respirator and filter replacement associated with routine use of EHFRs in healthcare settings. While most elastomeric respirator users reported that their respirator was available when needed, many did not report storing the device readily in the patient care area. Lack of availability was consistently associated with noncompliant discordant user status but was not additionally affected by job status or training frequency. Compliance with expected use was influenced by job status, particularly with

Table 3. Filter Change and Elastomeric Respirator Replacement Frequency Reported by Concordant Compared to Discordant EHFR Users ($n=432$)

| | *Concordant EHFR Users* | | *Discordant EHFR Users* | | |
|---|---|---|---|---|---|
| | n = *280* | *% of Group* | n = *152* | *% of Group* | *p-Value* |
| *The filters/cartridges on my reusable elastomeric respirator have been changed:* | | | | | **0.015** |
| Within the last year | 37 | 13.2 | 13 | 8.6 | |
| At least once before, but not in the last year | 46 | 16.4 | 13 | 8.6 | |
| Never[a] | 197 | 70.4 | 126 | 82.9 | |
| *Have you ever had to obtain a replacement reusable respirator?* | | | | | 0.059 |
| No | 254 | 90.7 | 129 | 84.9 | |
| Yes, because it was lost or stolen | 14 | 5.0 | 17 | 11.2 | |
| Yes, other reason[b] | 12 | 4.3 | 6 | 4.0 | |

[a]For subsequent analysis, filter change reported within the last year was combined with at least once before, but not in the last year, and compared to "never."
[b]"other reason" options included (1) material defect to the respirator, (2) need for a different size, or (3) respirator was contaminated.
*Note.* EHFR = elastomeric half-face respirator

Table 4. Adjusted Odds of Respirator Use Practice Among Discordant ($n=152$) Compared to Concordant EHFR Users ($n=280$)

| | *aOR*[a] | *CI* | *Stratified OR in Interaction Analysis* | *CI* |
|---|---|---|---|---|
| **Availability** | | | | |
| Respirator not always available | **3.62** | (2.28-5.74) | | |
| Nurses | | | 2.36 | (1.18-4.72) |
| Patient support/other | | | 5.13 | (2.16-12.21) |
| Providers and RTs | | | 5.11 | (2.05-12.69) |
| Training/fit-testing annually | | | 3.6 | (2.11-6.16) |
| Training/fit-testing less frequently than annually | | | 3.68 | (1.53-8.81) |
| **Storage location** | | | | |
| Respirator not stored in the patient care area | 1.24 | (0.79-1.95) | | |
| Nurses | | | 0.91 | (0.44-1.91) |
| Patient support/other | | | 0.72 | (0.31-1.66) |
| Providers and RTs | | | 3.2 | (1.37-7.45) |
| Training/fit-testing annually | | | 1.15 | (0.68-1.95) |
| Training/fit-testing less frequently than annually | | | 1.51 | (0.67-3.42) |
| **Storage technique**[b] | | | | |
| Respirator stored suboptimally | 1.02 | (0.66-1.56) | | |
| **Filter change frequency** | | | | |
| Never changed filters | **2.57** | (1.49-4.44) | | |
| Nurses | | | 5.03 | (1.61-15.75) |
| Patient support/other | | | 1.21 | (0.51-2.85) |
| Providers and RTs | | | 3.35 | (1.35-8.31) |
| Training/fit-testing annually | | | 2.63 | (1.40-4.95) |
| Training/fit-testing less frequently than annually | | | 2.42 | (0.91-6.44) |
| **Replacement respirator**[b] | | | | |
| Never obtained replacement respirator | 0.83 | (0.43-1.60) | | |

[a]Adjusted for job category, site, primary unit, frequency of fit-testing or training, and years worked in healthcare.
[b]No interaction analysis performed because of lack of statistically significant difference between concordant and discordant groups during earlier chi-square analysis.
*Note.* EHFR = elastomeric half-face respirator, aOR = adjusted odds ratio; CI = confidence interval.



more mobile workers reporting inconvenient storage location. Additionally, many elastomeric respirator users do not store their respirators according to the expected practice, although this was not associated with discordant user status.

Most healthcare elastomeric respirator users have never changed the filters on their respirators, and very few have obtained a replacement respirator. These logistical realities in one system's EHFR experience may predict compliance—or noncompliance—with expected respiratory protection practices more widely. Such observations may predict the utility then of EHFRs as a solution to N95 respirator shortages. Reported practices that were significantly different between concordant versus discordant users included ready availability, storage location, and frequency of filter change. This suggests that those issues, in particular, may be key logistical determinants of compliance with recommended practices in respiratory protection programs that include elastomeric devices.

## *Similarities with Other Studies*

Our study found similar associations between reported respirator availability and compliance with expected use practice seen previously in health care. In a study among nurses, allocating adequate storage space and ensuring that this storage space is used were factors that significantly influenced nurses' use of respiratory protection to prevent occupational transmission of respiratory illnesses.[14] In another study of clinicians and management leaders related to hospital respiratory protection, knowledge regarding storage of respirators was deemed to be an important competency for healthcare workers in respiratory protection.[15]

## *Storage of Respirators in Health Care*

In this study, healthcare workers were asked about methods of respirator storage compared to expected hospital practice at the time, which was to store the EHFR in a sealed plastic bag. While just over half of the respondents reported compliance with this practice, it was not associated with discordant status. This suggests that coherence with expected storage methods does not predict compliance with assigned respirator use. While storing EHFRs in sealed plastic bags may be suboptimal, storing them in sealed containers or individual storage bins, as OSHA suggests, may not be needed in a relatively clean healthcare environment.[16,17]

Currently, the only healthcare-specific respirator storage guidance focuses on disposable N95s. A 1995 position

paper by the Society for Healthcare Epidemiology of America, for example, suggested acceptable forms of overnight respirator storage may include hanging the respirator on a pegboard, placing it in a locker, or putting it in the pocket of a laboratory coat hung in a locker, citing no reason to place the respirator in a plastic bag—which previously had been considered an appropriate storage method—if it is being stored in a clean environment.[17] In the context of extended use and limited reuse of disposable N95 respirators, the Centers for Disease Control and Prevention (CDC) advises hanging used respirators in a designated storage area or keeping them in a clean, breathable container, such as a paper bag, between uses.[18] If EHFR storage is considered similarly to N95 storage, there is precedent for healthcare-focused storage guidance that does not include storage in a sealed or individual container. Ramifications of storage outside of a sealed container would largely have an impact on filter lifespan, as affected by humidity. Humidity in most well-resourced healthcare settings, however, is likely to be routinely controlled, making this less of a negative factor. The importance of keeping the face-piece protected from deformation, however, cannot be neglected. Thus, storage in a manner that prevents this must be assured.

## *Impact on Respirator Availability*

Our study participants reported infrequent filter change. The reasons for this can not be determined from our survey. Of those who had changed their filters within the past year ($n = 50$), most did so because they either asked to change them or they were told to do so. A third of those doing so reported they did so because the filters had become wet or visibly soiled or because it was hard to breathe (data not shown). It is possible that the filters should have been changed more frequently. In environments with heavy particulate loads, such as mining or construction, filter change frequency is expected to be much greater than in an environment like healthcare, where traditional loads of particulates are much lower.[17,19]

In a similar EHFR-based respiratory protection program at the Texas Center for Infectious Disease (TCID), which houses patients with active tuberculosis, filter cartridges are changed annually or when dirty, saturated with fluids, damaged, or difficult to breathe through.[7,20] The appropriate interval for filter changes of elastomeric respirators in healthcare environments is currently a research gap, but the interval of filter use may be longer than in industrial environments.

Finally, loss and theft of elastomeric respirators affect availability and must be anticipated. While costs associated with respirator replacement are potential barriers to elastomeric use, this study showed that very few healthcare workers reported obtaining a replacement respirator.

## *Options to Ensure Successful Use*

Various options may be considered to ensure elastomeric respirator storage for successful point-of-care use. At the institutional level, responsibility for storage may be centralized or left to the individual. The 2018 National Academies report suggested that when the number of workers involved is small, or when use of respiratory protective devices is "on demand," respirators could be assigned to workers who are individually responsible for storage of their respirators.[7]

The individual-based approach was the strategy in place for the healthcare workers in the present study, where 64% of workers reported that their respirator was "always" available, despite a significant portion of respondents reporting that their respirator was not stored in the immediate patient care area. Notably, these suboptimal storage practices were more frequently reported by providers and respiratory therapists, who are mobile workers. This also influenced their compliance with expected respirator use. Consequently, assurance that a mobile worker always has a respirator nearby may require securing it to their person or providing a dedicated cache of unassigned respirators of various sizes available for use in each unit. One institution has reported success with the former approach. The TCID has successfully implemented a strategy where healthcare workers carry their elastomeric respirators in shoulder carrying bags supplied by the employer.[7] This strategy provides an individual-focused mechanism for healthcare workers to always have access to their respirator. Alternatively, a plan in which the healthcare facility provides a cache of respirators in a dedicated storage area on each clinical unit would ensure that mobile healthcare workers will have access to clean, well-maintained respirators, but may be limited by lack of dedicated storage space.[7]

In a Canadian pilot study where elastomeric respirators were newly introduced, storage of respirators near to patient rooms was limited as was storage in clean supply and soiled utility rooms.[7,21] Thus, a central-based storage plan requires forethought and innovation. This has previously been accomplished in stocking protective gowns required for care of patients on contact precautions. Solutions in that arena have included integration of storage cabinets into walls so that workspace is optimally preserved.

## *Study Strengths and Limitations*

This study has several strengths. First, this is the only study in the literature of healthcare workers who (currently or previously) routinely use elastomeric respirators. The experiences from this population can help inform decisions and policies about elastomeric respirators in healthcare respiratory protection programs. The surveys were designed based on feedback from healthcare workers who routinely use elastomeric respirators, rather than from participants using them as part of a trial period or research study. Our population provides accounts of use from caregivers who use respirators regularly, with 20% of this user group reporting respirator use during at least 10% of their usual work time. This likely represents the frequency of respirator

use for healthcare workers caring for patients on airborne precautions in many urban hospital settings in the United States.

Our study also has several limitations. The results are based on self-reporting, which may provide biased information, and the study was not designed to include observation validation of practices among healthcare workers. Another limitation is classification of respirator users. At the time of questionnaire deployment, the hospital had begun transitioning certain clinical units out of elastomeric respirators because of concerns about noncompliance with use of assigned respirators, particularly among mobile staff such as physicians. This may have limited the number of participants who were "currently" using elastomeric respirators or may have confused participants as to what type of respirator they were assigned to use. Because of this, results among concordant users and discordant users are reported to provide comprehensive responses from all users. Thus, despite potential issues associated with new respirator assignment or discordant use, we were able to capture a broad range of experiences with elastomeric respirator use from a worker population familiar with their use.

## Conclusion

As part of a larger effort to evaluate the viability of elastomeric respirators as an alternative to N95 respirator use in healthcare, this study showed that lack of storage and ready point-of-use access are barriers, especially among mobile users. While most healthcare workers report that the respirator is available, discordant users were more likely to report barriers to availability. Availability of respirators clearly affects compliance with expected respirator use practices, and, if not addressed, limits potential for use of re-usable devices as an alternative to N95 respirators. Strategies to ensure ready availability and easy, secure storage of respirators, however, will permit inclusion of elastomeric respirators as a viable asset in pandemic planning and routine respiratory protection programs.

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## References

1. Siegel JD, Rhinehart E, Jackson M, Chiarello L, Health Care Infection Control Practices Advisory Committee. 2007 guideline for isolation precautions: preventing transmission of infectious agents in health care settings. *Am J Infect Control* 2007;35(10 Suppl 2):S65-S164.
2. Wizner K, Stradtman L, Novak D, Shaffer R. Prevalence of respiratory protective devices in U.S. health care facilities: implications for emergency preparedness. *Workplace Health Saf* 2016;64(8):359-368.
3. Srinivasan A, Jernign DB, Liedtke L, Strausbaugh L. Hospital preparedness for severe acute respiratory syndrome in the United States: views from a national survey of infectious diseases consultants. *Clin Infect Dis* 2004;39(2):272-274.
4. Beckman S, Materna B, Goldmacher S, et al. Evaluation of respiratory protection programs and practices in California hospitals during the 2009-2010 H1N1 influenza pandemic. *Am J Infect Control* 2013;41(11):1024-1031.
5. Bach M. Understanding respiratory protection options in healthcare: The overlooked elastomeric. July 6, 2017. Atlanta, GA: Centers for Disease Control and Prevention (CDC); 2017. https://blogs-cdc-gov.proxy-hs.researchport.umd.edu/niosh-science-blog/2017/07/06/elastomerics/.
6. Hines SE, Mueller N, Oliver M, Gucer P, McDiarmid M. Qualitative analysis of origins and evolution of an elastomeric respirator-based hospital respiratory protection program. *J Int Soc Respir Prot* 2017;34(2):95-110.
7. National Academies of Sciences, Engineering, and Medicine; Health and Medicine Division; Board on Health Sciences Policy; Committee on the Use of Elastomeric Respirators in Health Care; Clever LH, Rogers BME, Yost OC, Liverman CT, eds. *Reusable Elastomeric Respirators in Health Care: Considerations for Routine and Surge Use.* Washington, DC: National Academies Press; 2018.
8. Occupational Safety and Health Administration. Respiratory Protection Standard. OSHA 1910.134; Provisions on Storage (1910.134(h)(2)(i) and Inspection (1910.134(h)(3)(i)). https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_id=12716&p_table=standards. Accessed August 22, 2019.
9. Lippy B. Elastomeric Respirators: Lessons Learned from Other Industries. Presentation and comments presented at the March 22 public meeting of the National Academies of Sciences, Engineering, and Medicine Committee on the Use of Elastomeric Respirators in Health Care; Washington, DC; 2018.
10. Schmoldt M. Use of Elastomeric Respirators in High Hazard Industry. Presentation and comments presented at the March 22 public meeting of the National Academies of Sciences, Engineering, and Medicine Committee on the Use of Elastomeric Respirators in Health Care; Washington, DC; 2018.
11. Bessesen MT, Adams JC, Radonovich L, Anderson J. Disinfection of reusable elastomeric respirators by health care workers: a feasibility study and development of standard operating procedures. *Am J Infect Control* 2015;43(6):629-634.
12. Brown LM, Rogers B, Buckheit K, Curran JP. Evaluation of 9 health care organizations' respiratory protection programs and respiratory protective device practices: implications for adoption of elastomerics. *Am J Infect Control* 2018;46(3):350-352.
13. Hines SE, Brown C, Oliver M, et al. User acceptance of reusable respirators in health care. *Am J Infect Control* 2019;47(6):648-655.
14. Nichol K, Bigelow P, O'Brien-Pallas L, McGeer A, Manno M, Holness DL. The individual, environmental, and organizational factors that influence nurses' use of facial protec-

tion to prevent occupational transmission of communicable respiratory illness in acute care hospitals. *Am J Infect Control* 2008;36(7):481-487.
15. Rogers B, Buckheit K, Ostendorf J. Development of competencies for respiratory protection for health care workers. *Workplace Health Saf* 2019;67(2):56-67.
16. OSHA Office of Training and Education. Respiratory protection frequently asked questions. November 2004. https://www.osha.gov/dte/library/respirators/faq.html. Accessed August 22, 2019.
17. Decker MD. Respiratory protection standard: comments on OSHA's proposed revision. *Infect Control Hosp Epidemiol* 1995;16(6):365-371.
18. Centers for Disease Control (CDC). Recommended Guidance for Extended Use and Limited Reuse of N95 Filtering Facepiece Respirators in Healthcare Settings. National Institute for Occupational Safety and Health; 2014. https://www-cdc-gov.proxy-hs.researchport.umd.edu/niosh/topics/hcwcontrols/recommendedguidanceextuse.html#ref21.
19. Jensen PA, Lambert LA, Iademarco MF, Ridzon R; CDC. Guidelines for preventing the transmission of *Mycobacterium tuberculosis* in healthcare settings, 2005. *MMWR Recomm Rep* 2005;54(RR-17):1-141.
20. Kizilbash AC, Guenther C, Reed R, Mata D. Use of elastomeric masks at a TB hospital. Presentation and comments presented at the March 22 public meeting of the National Academies of Sciences, Engineering, and Medicine Committee on the Use of Elastomeric Respirators in Health Care; Washington, DC; 2018. http://nationalacademies.org/hmd/~/media/Files/Activity%20Files/Workforce/ElastomericRespirators/Meeting%202/TCID.pdf. Accessed August 22, 2019.
21. Ciconte R, Danyluk Q. Assessment and Determination of Practical Considerations for Widescale Utlization of Elastomeric Half-facepiece Respirators during a Pandemic or Outbreak Situation. Report No.: RS2011-IG13. Richmond, BC, Canada: WorkSafe BC Research Services; 2013.

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