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RESEARCH ARTICLE

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Elastomeric half-mask respirator disinfection practices among healthcare personnel

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Abstract

Background: Disposable N95 respirator shortages during the COVID-19 and 2009 H1N1 influenza pandemics highlighted the need for reusable alternatives, such as elastomeric half-mask respirators (EHMRs). Two US medical organizations deployed reusable EHMRs during the COVID-19 response. In addition to wipe-based disinfection following patient care episodes expected per local policies at both organizations, postshift centralized cleaning and disinfection (C&D) was expected at one site (A), permitting shared-pool EHMR use, and optional at the other (Site B), where EHMRs were issued to individuals. Using a survey, we evaluated disinfection practices reported by EHMR users and predictors of disinfection behaviors and perceptions.

Methods: Surveys assessed EHMR disinfection practices, occupational characteristics, EHMR use frequency, training, and individual-issue versus shared-pool EHMR use.

Results: Of 1080 EHMR users completing the survey, 76% reported that they disinfect the EHMR after each patient encounter, which was the expected practice at both sites. Increasing EHMR use, recall of disinfection training, and work in intensive care or emergency settings significantly influenced higher reporting of this practice. 36% of respondents reported using centralized C&D, although reporting was higher at the site (A) where this was expected (53%). Confidence in cleanliness of the EHMR following centralized C&D was not influenced by individual versus shared-pool EHMR issue.

Conclusions: Most EHMR users reported adherence with expected post-care individual-based disinfection of EHMRs but did not necessarily use standardized, centralized C&D. Future efforts to limit reliance on behavior related to respirator disinfection may improve EHMR implementation in healthcare to avert dependence on single-use, disposable N95 respirators.

KEYWORDS

central sterile processing, cleaning, decontamination, disinfection, elastomeric respirators, healthcare personnel, N95 filtering facepiece respirators, occupational safety

1 | INTRODUCTION

Shortages of N95 filtering facepiece respirators (N95 FFRs) during the coronavirus 2019 (COVID-19) and 2009 H1N1 influenza pandemics led to temporary practices of extended N95 FFR use, reuse, and costly and laborious efforts to decontaminate and reuse disposable respirators.[1,2] Healthcare environments have traditionally relied on disposable N95 FFRs for respiratory protection. Reusable respirators, such as elastomeric half-mask respirators (EHMRs) are available, however, and are designed to be repeatedly decontaminated, which includes disassembly, cleaning, disinfection, and reassembly.[3] In 2018, the National Academies of Science, Engineering, and Medicine (NASEM) concluded that EHMRs were appropriate for use in healthcare settings in both routine and crisis scenarios, provided that certain logistics of implementation were addressed, including cleaning and disinfection.[4]

In contrast to general industry, where workers use respirators to protect against noninfectious particles, workers in healthcare typically use respirators as protection from respirable infectious particles. Microbes that cause communicable disease and can be transmitted through the air may contaminate the surfaces of a respirator. If the surfaces of a reusable EHMR are not disinfected after use, the respirator itself, depending on the organism, might contribute to fomite transmission of disease to healthcare personnel (HCP) or patients.[4,5] In a pre-COVID-19 study of hospital EHMR users who were issued their own respirators and were expected to clean, disinfect, carry, and store them, 52.3% reported always wiping down the surfaces of the respirator with a disinfectant wipe after each use, and only 9.3% reported additional cleaning of the respirator with an approved detergent to remove soiling agents beyond microbial contaminants such as facial oils on at least a weekly basis.[5] Additionally, in laboratory-based studies where elastomeric facemasks were contaminated with influenza virus and simulated facial contaminants, use of conventional hospital disinfectant wipes did not consistently eliminate viable influenza virus from respirator surfaces or remove simulated facial contaminants.[6,7] In contrast, additional cleaning with detergent consistently eliminated both virus and facial contaminants.[6]

Even before the COVID-19 pandemic, infection preventionists and occupational health professionals expressed concerns regarding the practicality of implementing reusable respirator cleaning and disinfection (C&D) protocols by HCP in hospital settings and how effectively HCP disinfected their respirators using standard hospital disinfectant wipes.[8–10] Such concerns led to efforts to shift C&D responsibilities away from individual HCP towards professional C&D staff, using standardized C&D protocols.[11–14] These protocols, drafted early in 2020, relied on a limited amount of published literature[9,15,16] and innovation from hospital staff, as respirator manufacturer instructions for use (IFU) often failed to provide guidance tailored to healthcare environments.[15,16]

Relying on these published protocols and manufacturer IFU, two US medical organizations implemented respiratory protection programs (RPP) including EHMRs. Both organizations incorporated centralized standardized C&D through their Central Sterile Processing (CSP) departments but also relied on HCP to wipe the EHMR surfaces with disinfectant wipes after each respirator doffing.[11,12,17] Such protocols promoted safe infection control practices but still relied on HCP behavior to maintain these strategies.

HCP and patient safety practices and outcomes often rely heavily on HCP risk-based perceptions and subsequent behavior and compliance with expected practices.[18–20] While solutions exist to overcome potential logistical barriers of reusable respirator C&D, HCP compliance with consistent C&D remains unclear. Like handwashing, optimal practice would include 100% compliance with disinfecting the respirator after doffing and, where available, consistent use of centralized, standardized C&D and respirator reprocessing. To gain broader acceptance by infection preventionists and occupational health leaders, solutions to overcome respirator C&D barriers should demonstrate that HCP will enact the behavior expected of them.[4,8]

As part of a larger study to understand EHMR use in healthcare, we aimed to evaluate self-reported C&D practices and perceptions among EHMR users at two medical organizations using EHMRs during the COVID-19 pandemic that had also established centralized C&D protocols. We surveyed HCP at one large medical center and another medical system with eight participating hospitals about their EHMR disinfection practices, knowledge of the C&D protocols, and confidence in the cleanliness of their respirator. We hypothesized that HCP would report higher adherence to using wipes to disinfect the respirator after each patient care episode, due to a perceived greater risk, in contrast to that observed during prepandemic EHMR use.[5] By understanding how well HCP adhere to such protocols, these findings may inform cleaning and disinfection components of future respiratory protection strategies incorporating reusable EHMRs.

2 | MATERIALS AND METHODS

2.1 | Sample and setting

We conducted this survey from April to June 2021 (during the US public health emergency declaration for COVID-19) at two medical organizations in the eastern US Site A, a large medical center,

employs over 7500 employees, 1300 faculty physicians and 950 residents. This center admits more than 26,000 patients annually into its 800 beds, which includes a pediatric, neonatal, and six adult critical care units. Site B, a medical system including eight individual hospitals, employs over 3700 employees and more than 1000 physicians and admits approximately 24,000 patients annually to 552 beds.

During this time, HCP at both sites were required to wear respiratory protection during any aerosol-generating procedure[21] or while caring for patients on airborne or enhanced droplet precautions. Because EHMRs are tight-fitting respirators, HCP were only permitted to use the respirators for which they were fit-tested and trained to use. Both sites had long-standing OSHA-compliant RPPs that included written policies, program administrators, procedures for hazard evaluation and respirator selection, use of respirators approved by the National Institute for Occupational Safety and Health, medical evaluation of respirator wearers, fit-testing, procedures for storage and maintenance of respirators, training, program evaluation, and recordkeeping elements.[22,23] Before the COVID-19 pandemic, both sites incorporated a hierarchy of control elements related to care of patients with conditions requiring use of airborne precautions, such as airborne isolation rooms with negative pressure ventilation and use of respirators.[24] Site A had experience using EHMRs dating back to 2009 but primarily used N95 FFRs and PAPRs in the months leading up to COVID-19.[8] Site B added EHMRs to their RPP for the first time in 2020 as part of COVID-19 response.

Both sites' RPPs adhered to recommendations from the Centers for Disease Control and Prevention for elastomeric respirator use strategies during conventional and surge demand situations, including reuse of EHMR filter cartridges[25] Site A utilized a shared pool of EHMRs. Site A's policy instructed HCP to return their EHMRs at the end of each shift for C&D by the CSP department. This process included detergent-based cleaning and high-level disinfection of EHMRs between users, except in the emergency department (ED), where each HCP was provided an individually issued, personal EHMR.[11] Site B also included a centralized C&D program sponsored by the CSP department, although use of this program was optional at the time of survey.[17] Site B had converted from a shared EHMR program to each HCP being provided their own EHMR. At both sites, local policies expected HCP to wipe the surfaces of their EHMRs with disinfectant wipes after each doffing episode. Both sites used disinfectants for both wipe and central disinfection procedures were included in the EPA List N for use against COVID-19.[26] Both sites communicated with the manufacturers of their respective EHMRs to confirm that the disinfectants to be used at each site were compatible with the EHMR non-filter components. Site A used the 3M 7500 series EHMR with 3M P100 7093 filter cartridges, where the filter was enclosed in a rectangular plastic casing. Site B used the MSA Advantage 200LS EHMR with MSA Advantage Low Profile P100 respirator filter cartridges, where the filter was housed in a circular plastic grid-like casing. At Site A, HCP used Oxivir® TB wipes, which contained hydrogen peroxide as the active ingredient. HCP at Site B wiped their EHMRs with PDI Super Sani-Cloth® or Sani-Cloth AF3 wipes, which contained quaternary ammonium compounds as active ingredients. For the central decontamination procedures, Site A cleaned EHMRs with a neutral enzymatic detergent containing subtilisins (Endozime®), followed by high-level disinfection with a hydrogen peroxide-based product (RESERT®).[11] Site B centrally cleaned and disinfected EHMRs using a quaternary ammonium compound-based product (MSA Confidence Plus® 2 Germicidal Cleaner).[17] At the time of survey, local policies instructed HCP to doff the respirator after each patient care encounter. While guidance was available, extended use (wherein respirators are worn continuously and between multiple patients) was uncommon.[19]

Both sites provided training in EHMR disinfection to EHMR users. Site A provided a handout describing how to disinfect the EHMR using disinfectant wipes.[11] Site B provided videos that demonstrated EHMR disinfection, and educators and the employee health team were available for staff questions.[17] Neither site incorporated knowledge or practice checks to confirm understanding of the disinfection process.

The survey was sent to 2419 and 2257 eligible HCP at Sites A and B, respectively. The response volume of 480 surveys from Site A and 600 from Site B was determined before distribution based upon estimated effect sizes as found in a previous study and upon budgetary plans.[27] Eligible HCP were invited to participate in the survey through email from the REDCap online database system.[28,29] Survey responses were captured through REDCap, and the survey ended when the predetermined volume was reached. Data were downloaded from each site and combined for analysis. This study was reviewed and approved by each site's local Institutional Review Boards and granted waivers of written informed consent for this minimal risk study.[1]

2.2 | Measures

2.2.1 | HCP EHMR survey

A 55-question survey assessing current HCP EHMR use, perceptions, and practices was designed in the fall of 2020. The survey incorporated questions from prior respirator use surveys and new questions tailored to assess hospital-specific practices.[27,30,31] Participants responded to questions about their education level, years of service, role, work setting, methods of respirator training and their perception of adequacy, and EHMR disinfection. Supporting Information: Table S1 shows survey questions used to assess EHMR disinfection practices. The questionnaire was designed to be completed in 10–20 min and was administered using the REDCap platform.

2.2.2 | Assessment of EHMR use and disinfection practice

Participants were asked "who does the disinfection of the EHMR" and could select multiple options. Response choices included: "you,"

"Environmental Services" (which did not perform respirator C&D at either site), "CSP," "other," and "don't know." For analysis, these responses were collapsed to (1) self, (2) CSP or other, and (3) don't know. We assumed that some HCP may not have known the specific name of the department tasked with disinfecting the EHMRs but knew that centralized disinfection occurred. Despite the varying expectations for use of centralized C&D at the two sites, both sites expected that individual HCP would disinfect the EHMRs with disinfectant wipes after each patient encounter. HCP were also asked to answer the question, "At what point do you personally disinfect your respirator?", which included multiple response options of "at the end of the shift," "after each patient encounter," "hourly," and "other." Disinfection following each patient encounter was classified as the best answer and selected as an outcome of interest. Confidence in EHMR cleanliness and disinfection by CSP was rated as "fully confident," "somewhat confident," "a little confident," and "not confident at all." "Fully confident" was classified as the best answer and used for analysis. Although multiple questions asked about EHMR disinfection, no questions asked specifically about EHMR "cleaning," such as use of a detergent to remove soiling agents. Thus, results are expressed based on how HCP responded to questions that included the term "disinfection." Also, when referring to the centralized decontamination programs themselves in this paper, not as a result of a survey question, the term C&D is used in this text. Use frequency was determined by how many times the participants thought they wore (on/off) the EHMR during a shift (0–1, 2–5, or 5+ times) and estimating the total percentage of time during their shift that HCP wore their respirators (<25%, 25%–50%, 50%–75%, or >75% of shift). HCP were also asked if they had received training in disinfecting the EHMR (yes or no).

2.3 | Analysis

Demographics, EHMR training, EHMR use, EHMR disinfection practices, and confidence were analyzed using frequencies. Comparisons among demographics, EHMR use, training, and disinfection practices were made using multivariate logistic regression. Bivariate modeling occurred between each variable and outcome. Multivariate models of the outcomes were built by adding significant predictors while comparing Akaike Information Criteria and Bayesean Information Criteria values with those from the null model. For the question of when the respirator was disinfected, the minimum correct answer at both sites was "after each patient encounter." Thus, the odds of selecting "disinfect after each encounter" was calculated. To assess predictors of use of centralized C&D, the odds of selecting the response option that "CSP or other" disinfected the EHMR was calculated. Finally, to understand what influenced confidence in cleanliness of the EHMRs when cleaned and disinfected by CSP, the odds of reporting "full confidence" (compared to somewhat confident or less) in EHMR cleanliness was calculated. Covariates included in analysis of disinfection practices included site, HCP role (nurses, physicians or advanced practice providers (defined here as "providers"), respiratory therapists, or other HCP (categorized here as "other"), primary unit, recall of training in EHMR disinfection, frequency of use, and receipt of own respirator (as opposed shared pool use). These analyses were conducted using IBM® SPSS® Statistics for Windows version 23 (IBM Corp.).

3 | RESULTS

A total of 1080 HCP completed the survey with 480 (44%) from Site A and 600 (56%) from Site B (Table 1). Most HCP from both sites reported they had been in their current profession for 5 years or more (56%). Most respondents were nurses (49%) and physicians and advanced practice providers ("providers") (25%), and they primarily worked in intensive care units (ICUs) or EDs (50%), especially at Site A (63%) compared to Site B (39%). Site B respondents more often reported primarily working in units other than ICU, ED, medical/surgical, or pediatric floors (46%). The majority (89%) of respondents at Site B reported receiving their own EHMR, in line with the hospital's individual-issue respirator policy. Thirty-seven percent of respondents at Site A reported they were provided their own EHMR, where the protocol was for shared pool respirator distribution, except among HCP working in the ED, who received individual-issued respirators. There were no significant differences in the proportions of frequencies of use or total percentage of time wearing an EHMR. Most HCP recalled being trained in how to disinfect their EHMR (74%). The majority of HCP reported disinfecting their respirators following each patient encounter (76%). The majority of respondents reported disinfecting their EHMR themselves (84%). In addition, they also reported CSP or others disinfecting the EHMR, with a significant difference between the two sites (Site A, 53%, Site B, 24%, $p < 0.001$). Many HCP reported feeling fully confident their respirator was clean and disinfected each time the EHMR was returned from CSP; however, 50% from Site A reported feeling only somewhat confident.

3.1 | Disinfecting following each patient encounter

Examining the relationship between HCP and disinfecting their EHMR following each patient encounter, significant independent effects were found among the sites, roles, primary units, training, and EHMR use (Table 2). For Site B (with the individually issued EHMR program and optional centralized C&D), HCP were 33% less likely to report disinfecting their respirator after each encounter than Site A (with the shared EHMR pool and expected per policy centralized C&D (OR: 0.67, 95% confidence interval [CI]: 0.45–0.99). Controlling for site differences, providers were less likely to select disinfection following patient encounters compared to nurses (OR = 0.51, 95% CI: 0.35–0.74), as were those working in medical/surgical and pediatric floors compared to those in ICUs and Eds. Those who recalled receiving training in disinfecting their EHMRs were three times as likely to select disinfection after each patient encounter compared to

TABLE 1 Occupational and respirator use characteristics.

		Site				Total		
		A (*n* = 480)		B (*n* = 600)		(*n* = 1080)		
		n	%	*n*	%	*n*	%	
What is the length of time you have been in your current profession?	<1 year	47	10%	40	7%	87	8%	[***]
	1–<2 years	67	14%	58	10%	125	12%	
	2–4 years	140	29%	121	20%	261	24%	
	5+ years	226	47%	378	63%	604	56%	
Role	Nurses	284	59%	245	41%	529	49%	[***]
	Providers (physicians and advanced practice providers)	95	20%	177	30%	272	25%	
	Respiratory therapists	26	5%	33	6%	59	5%	
	Other	73	15%	140	23%	213	20%	
Primary unit	ICU and ED	301	63%	235	39%	536	50%	[***]
	Medical/Surgical and Pediatric floors	70	15%	80	13%	150	14%	
	other	104	22%	276	46%	380	35%	
Were you provided your own EHMR?	Yes	178	37%	534	89%	712	66%	[***]
How many times do you think you wear (on/off) your EHMR during a shift, on average?	0–1 time	161	34%	205	34%	366	34%	
	2–5 times	161	34%	181	30%	342	32%	
	5 times or more	150	31%	184	31%	334	31%	
What is the total percent of time during your shift that you wear your respirator?	<25% of my shift	254	53%	328	55%	582	54%	
	25%–50% of my shift	148	31%	143	24%	291	27%	
	50%–75% of my shift	51	11%	55	9%	106	10%	
	>75% of my shift	23	5%	41	7%	64	6%	
Were you trained in how to disinfect the EHMR?	Yes	323	67%	471	79%	794	74%	[***]
	No or don't know	154	33%	109	21%	263	26%	
Who does the disinfection of the EHMR (multiselect)?	Yourself	394	82%	511	85%	905	84%	
	CSP or Other	252	53%	141	24%	393	36%	[***]
	Don't know	49	10%	36	6%	85	8%	[**]
At what point do you personally disinfect your respirator? (Multiselect)	At end of each shift	115	24%	158	26%	273	25%	
	After each patient encounter	393	82%	423	71%	816	76%	[***]
	Hourly	10	2%	15	3%	25	2%	
	Other	37	8%	87	15%	124	11%	[***]

TABLE 1 (Continued)

		Site A (*n* = 480)		Site B (*n* = 600)		Total (*n* = 1080)		
		n	%	*n*	%	*n*	%	
How confident are you that your respirator is clean and disinfected each time it comes off central processing?	Fully confident	171	36%	277	46%	448	41%	[***]
	Somewhat confident	242	50%	173	29%	415	38%	
	A little confident	48	10%	52	9%	100	9%	
	Not confident at all	18	4%	28	5%	46	4%	

Abbreviations: CSP, central sterile processing department; ED, emergency department; EHMR, elastomeric half-mask respirator; ICU, intensive care unit.
**$p < 0.01$; ***$p < 0.001$.

those who reported no training or did not know (OR: 3.07, 95% CI: 2.18–4.33). Compared to those wearing their EHMR 0-1 time per shift, those wearing their EHMR 2–5 times (OR: 1.54, 95% CI: 1.05–2.24) or more than five times (OR = 1.61, 95% CI: 1.09–2.37) in a shift were more likely to report disinfecting their EHMR following each patient encounter.

3.2 | Using central sterile processing for cleaning and disinfecting the EHMR

Several factors were found to be associated with the use of CSP for disinfecting the EHMR (Table 3). Those at Site B (with the individually issued EHMR program and optional centralized C&D) were 45% less likely to report using CSP for disinfecting their EHMR compared to Site A (with the shared EHMR pool and expected centralized C&D) (OR: 0.55, 95% CI: 0.39–0.78). Controlling for differences in site, compared to nurses and HCP working in ICU & ED, providers and those working in medical/surgical and pediatric floors were both one-third less likely to select using CSP for disinfecting their EHMRs (95% CI: 0.41–0.98). Those who reported being provided their own EHMR (OR = 0.42, 95% CI: 0.30–0.59) were also significantly less likely to report using CSP for disinfection (Table 4).

3.3 | Fully confident in EHMR disinfection by central sterile processing

HCP from Site B (OR = 1.58, 95% CI: 1.13–2.20) and HCP who reported using CSP for disinfection (OR = 1.83, 95% CI: 1.36–2.46) reported high confidence in EHMR disinfection by CSP, compared to Site A and non-CSP users, respectively. Controlling for site and using CSP or other for disinfection, significant independent differences remain for role, primary unit, and training. Providers were 55% more likely to be fully confident compared to nurses. Those who recalled being trained in how to disinfect their EHMR were twice as likely to report being fully confident as those who were not trained.

4 | DISCUSSION

We evaluated self-reported disinfection practices and perceptions among HCP at medical organizations using EHMRs during the COVID-19 pandemic that had also established centralized C&D protocols. Consistent with our hypothesis and notably improved compared to prepandemic reporting, we found that most HCP reported disinfecting their respirators after each patient encounter (76%), and 84% reported that they personally disinfected the respirator. Only 36% of HCP reported that respirators were disinfected centrally. In both instances, reporting was influenced significantly by hospital site, job type, and unit type. This suggests that even when structured C&D policies and procedures exist, additional occupational and other external factors may influence compliance with expected practice.

Significant predictors of disinfecting the respirator after each patient encounter included hospital site, job and unit type, training content, and frequency of use. HCP at Site B reported this practice less frequently than at Site A, which had a shared pool of EHMRs and expected centralized C&D. EHMRs were first introduced at Site B during COVID-19, and policy guiding their use varied over the first 12 months of the pandemic, shifting from centralized C&D with shared supply to individual-based disinfection with optional centralized C&D.[17] It is possible that policy fluctuation or oversight in compliance may have influenced differential reporting by site. Alternatively, EHMR users from Site B, who may have used them only in procedural suites, may have dropped them off for centralized C&D immediately after use and not wiped down the respirators themselves. This would have been an acceptable practice. Also, independent providers (physicians and advanced practice providers) were less likely to disinfect the respirator after each patient

TABLE 2 Odds of selecting disinfect after each patient encounter ($n = 1026$).

		OR	95% confidence interval for odds ratio		
			Lower	Upper	
	Intercept	3.20	2.07	4.93	[***]
Site	B	0.67	0.45	0.99	[*]
	A	1.00			
Role	Other	0.80	0.52	1.22	
	Respiratory therapists	0.68	0.32	1.41	
	Providers	0.51	0.35	0.74	[***]
	Nurses	1.00			
Primary Unit	Other	0.61	0.42	0.88	[**]
	Medical/Surgical and Pediatric floors	0.48	0.31	0.75	[***]
	ICU and ED	1.00			
Were you trained in how to disinfect the EHMR?	Yes	3.07	2.18	4.33	[***]
	No or Don't know	1.00			
How many times do you think you wear (on/off) your EHMR during a shift, on average?	Greater than 5 times	1.61	1.09	2.37	[*]
	2–5 times	1.54	1.05	2.24	[*]
	0–1 times	1.00			
Were you provided your own EHMR?	Own EHMR	0.75	0.49	1.14	
	Not Own EHMR	1.00			

Abbreviations: CSP, central sterile processing department; ED, emergency department; EHMR, elastomeric half-mask respirator; ICU, intensive care unit.
*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

encounter compared to nurses. This finding is consistent with other studies that have found less adherent hand hygiene and personal protective equipment (PPE) use practices among physicians.[32–35] This may result from similar barriers to hand hygiene compliance, such as workload, time limitations, poor role modeling by others or from perceived ease and utility.[34,36]

Work in an ICU or ED and increased use frequency were both significantly associated with higher reporting of disinfecting after each patient encounter. Due to the higher acuity of patient care needs in ICU/ED environments, it is possible that HCP experience more frequent use of respiratory protection, with potentially more risk and perhaps more direct oversight. Additionally, workers in these environments may perceive greater risks to occupational exposures and greater knowledge and confidence with EHMR use, influencing compliance with expected protocols.[27,32,37] Similar factors might relate to understanding risks that a contaminated respirator may pose to a user, also influencing compliance with disinfection practices. Finally, whether someone was individually issued a personal EHMR did not significantly influence reporting of wiping the respirator after each use. This suggests that compliance with expected post-use disinfection is not significantly impacted by having an individually issued respirator or having a shared pool in which respirators are also centrally cleaned and disinfected.

HCP reported lower use of central EHMR C&D than we expected. Site differences were not surprising, as use of centralized C&D was optional at Site B at the time of the survey. However, only 50% of participants from Site A reported that the respirators were disinfected by CSP or other, despite the policy expectation. This behavior among Site A HCP may reflect a desire among EHMR users to keep their own respirators, a lowered perception of fomite transmission risk, or complacency with safety policy. As seen for disinfecting the respirator after each use, providers and HCP in

TABLE 3 Odds of using central sterile processing for disinfection (n = 1026).

			95% confidence interval for odds ratio		
		OR	Lower	Upper	
	Intercept	1.82	1.23	2.70	
Site	B	0.55	0.39	0.78	[***]
	A	1.00			
Role	Other	0.78	0.52	1.15	
	Respiratory therapists	1.76	0.97	3.22	
	Providers	0.68	0.47	0.97	[*]
	Nurses	1.00			
Primary Unit	Other	0.89	0.64	1.24	
	Medical/Surgical and Pediatric floors	0.64	0.41	0.98	[*]
	ICU and ED	1.00			
Were you trained in how to disinfect the EHMR?	Yes	0.82	0.59	1.12	
	No or Don't know	1.00			
How many times do you think you wear (on/off) your EHMR during a shift, on average?	Greater than 5 times	0.76	0.54	1.09	
	2–5 times	0.90	0.64	1.27	
	0–1 times	1.00			
Were you provided your own EHMR?	Yes	0.42	0.30	0.59	[***]
	No	1.00			

Abbreviations: CSP, central sterile processing department; ED, emergency department; EHMR, elastomeric half-mask respirator; ICU, intensive care unit.
*p < 0.05; ***p < 0.001.

medical/surgical units reported centralized disinfection less often, likely reflecting similar behavioral drivers.

Importantly, HCP who reported having an individually issued EHMR were less likely to report use of centralized disinfection. They were not, however, less likely to report confidence in the cleanliness and disinfection status of the respirators after centralized processing. This suggests that their lack of centralized C&D use was not being driven by a perception that this process was ineffective. Individual respirator issue also did not negatively influence reporting of disinfecting after each use. Thus, if hospitals issue respirators to individuals, HCP may be less likely to use centralized C&D, even if it is expected of them. This is likely due to the additional behaviors required of HCP to enact the steps needed, such as on-person transportation,[38] drop-off of EHMRs, and retrieval following C&D.

Interestingly, among participants who acknowledged that EHMRs were disinfected centrally, confidence in respirator cleanliness and disinfection status was more often reported among HCP from Site B and among providers. At Site B, de novo introduction of EHMRs involved multiple training modalities, including videos and the visible presence of the perioperative department, who led the decontamination effort.[17] At Site A, HCP may have felt reluctant to use a decontaminated respirator that had been used by another person, even though a rigorous C&D process existed. Although a "Shared Respirator Information Sheet" to answer questions about the process existed,[11] it is unclear how widely this was disseminated or if people read it. Prior literature suggests that video-based respirator education may predict better performance months later compared to printed training materials.[39] Use of a practice or competence validation would have clarified the effectiveness of the disinfection training modalities at both sites and should be studied in future respiratory protection studies.[37] While 74% reporting of recall of training in disinfection was imperfect, this

TABLE 4 Odds of reporting full confidence in EHMR disinfection by central sterile processing ($n = 971$).

			95% confidence interval for odds ratio		
		OR	Lower	Upper	
	Intercept	0.18	0.12	0.28	[***]
Site	B	1.58	1.13	2.20	[***]
	A	1.00			
Who disinfects your EHMR (CSP)	Yes	1.83	1.36	2.46	[***]
	No	1.00			
Role	Other	1.99	1.38	2.88	[***]
	Respiratory therapists	1.22	0.67	2.23	
	Providers	1.55	1.11	2.17	[*]
	Nurses	1.00			
Primary unit	Other	1.04	0.76	1.42	
	Medical/Surgical and Pediatric floors	1.01	0.68	1.50	
	ICU and ED	1.00			
How many times do you think you wear (on/off) your EHMR during a shift, on average?	Greater than 5 times	0.94	0.67	1.32	
	2–5 times	0.97	0.70	1.34	
	0–1 times	1.00			
Were you trained in how to disinfect the EHMR?	Yes	2.16	1.56	2.98	[***]
	No or Don't know	1.00			
Were you provided your own EHMR?	Own EHMR	1.38	0.97	1.96	
	Not Own EHMR	1.00			

Abbreviations: CSP, central sterile processing department; ED, emergency department; EHMR, elastomeric half-mask respirator; ICU, intensive care unit.
*$p < 0.05$; ***$p < 0.001$.

percentage is similar in scale to prior studies of HCP recall of annual respirator training.[40] Although fewer providers utilized the central C&D service compared to nurses, they reported being more confident in the cleanliness and disinfection status of the centrally decontaminated EHMRs. It is unclear why this occurred, unless the providers had more experience in the use of centrally decontaminated medical instruments, understood the steps of the C&D process better, or had more belief in the good faith efforts of the safety and infection control departments.

Only two studies have evaluated HCP disinfection behavior with reusable respirators. In a Canadian pilot study where HCP were expected to wipe the respirator surfaces after patient care encounters and drop-off at the end of shift for centralized C&D, HCP reported challenges in having enough time to wipe the respirator between care duties.[9] In a different quantitative assessment of compliance with the expected policy of always wiping the respirator after each patient encounter, only 52% of HCP reported always and 22% reported usually doing so.[5] Although asked in a different manner in the current study, adherence with expected policy was higher compared to this prepandemic study, which was performed in an environment with individually issued respirators. Like the prepandemic study, our study observed consistent reporting from providers of incomplete disinfection practices. This raises the question of how hospitals can improve provider compliance with

safety behaviors—potentially through process simplification, improved training, or use of departmental PPE champions.[10,36,41]

This study has several limitations. First, we analyzed self-reported behaviors and not direct observation. Actual practices may be different than what was reported, as has previously been seen in hand hygiene studies.[42,43] Second, we classified "disinfect after each patient encounter" as the best answer to the question "When do you disinfect your respirator." It is possible that some HCP practiced extended EHMR use, which was an accepted practice at the beginning of pandemic during "crisis/contingency" scenarios.[44] Thus, we may have misclassified responses reflecting extended use as noncompliant when such responses may have been congruous with temporary hospital policy. However, the survey occurred in the spring/summer of 2021, when both sites were no longer in crisis/contingency mode.[45] Thus, extended use of EHMRs should not have occurred at this time. Additionally, we assumed that self-reported knowledge of CSP respirator disinfection indicated that HCP were using centralized EHMR C&D, which may be inaccurate. Finally, this study examined responses among hospital workers. It is unclear if similar response patterns would occur with HCP from other healthcare settings, such as ambulatory services, nursing homes, or dental practices. This may limit generalizability to these nonhospital settings.

Our study also has several strengths. The survey occurred in the spring/summer of 2021 at a time during the COVID-19 pandemic when staff had experience with COVID-19 patient care and the initial 2020 chaos of global respirator shortages had decreased. Therefore, our findings likely reflect behavior patterns more consistent with usual circumstances, in contrast to behavior at the beginning of the pandemic, when HCP may have perceived higher risk and practiced meticulous infection control techniques.[46] Further, these hospital settings were not facing overwhelming patient volumes at the time of the survey, which might have influenced HCP time constraints related to respirator disinfection if HCP behavior had been assessed at the start of the COVID-19 pandemic. Similarly, disinfectant supplies were readily available during the spring/summer of 2021; thus, availability of disinfectant supplies should not have impacted responses. Notably, these data come from the largest survey of HCP using EHMRs in clinical practice to date. Importantly, these findings provide an evidence base to guide decision-making about future C&D processes and practices and compliance methods for EHMRs in healthcare settings, specifically. Finally, this study incorporates experiences of two large medical organizations which had different methods of implementation and still saw similar EHMR user disinfection patterns (Table 1).[11,12,17] This finding supports generalizability to other US hospital environments.

Our findings have several implications. Even with best practices of centralized EHMR C&D with postdoffing, and individual-based disinfection, we still see that reliance on individual behavior—although improved during the COVID-19 pandemic—is imperfect. If this were a radiological threat, a visible threat such as blood, or a threat leading to a higher mortality rate such as Ebola virus disease, compliance with expected disinfection practices might be higher.[47] Ideally, hospital-based EHMR decontamination strategies would not rely on human behavior as the primary exposure control. Rather, with enough supply, administrative solutions exist wherein a HCP could simply doff the respirator in a soiled bin after reuse, avoiding the step of personal disinfection, with subsequent respirator reprocessing in a central location using a standardized protocol.[9,14] Hospital RPP leaders need more explicit, evidence-based guidance from respirator manufacturers and scientists on practical, validated standardized C&D methods and implementation and reuse strategies. Such efforts might facilitate efficient integration of EHMR C&D into existing hospital disinfection efforts, such as ultraviolet germicidal irradiation[48] and hydrogen peroxide-based strategies, limiting the opportunities for failure points throughout the system.

Under the US OSHA respiratory protection standard, the employer bears the duty to ensure employees are protected.[23] This project studied EHMR use at two institutions that were committed and aware of their responsibilities, as employers, to provide respiratory protection. The actions of the employers may have contributed to safety cultures that influenced the disinfection practices reported here. A previous study by the same authors found the need to develop and maintain RPPs, among other initiatives, to not only positively influence safety climate perceptions, but also support participation in consistent PPE practices among HCP.[49] Specifically, management oversight and organizational support and dissemination of the RPP has been positively correlated with health employees' perceptions regarding how their employer prioritizes health and safety.[50] Further, a deployment of EHMRs within an ambulatory setting during the COVID-19 pandemic suggested the importance of updating and having an RPP in place before the rollout of new EHMRs to support employee adherence to required PPE use and maintenance.[51]

Although disinfection of respirators has not been the specific focus, prior studies have shown that ineffective use of PPE is impacted when employees perceive it [the PPE] to be a low priority for management.[52,53] Therefore, organizational support and oversight of the RPP to ensure adherence within all components may be useful to not only promote compliance with specific decontamination practices but may also provide broader support for the culture around reusable respiratory protection in the workplace.

In summary, HCP reported high compliance with expected post-care disinfection of EHMRs but did not necessarily use centralized C&D that was available. Future efforts to incorporate EHMRs should tailor implementation efforts to ensure that providers and non-ICU/ED workers understand the need for C&D and the expected policies. Future efforts to limit exclusive reliance on human behavior related to respirator C&D will further improve EHMR implementation in healthcare as a solution to reliance on single-use, disposable N95 FFRs, which create environmental waste, cost more, and face unreliable supply during demand situation.

AUTHOR CONTRIBUTIONS

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Waltenbaugh, Meghan Napoli, Caitlin McClain, Margaret Sietsema, and Rohan Fernando. *The acquisition, analysis, or interpretation of data for the work*: All authors. *Drafting the work or revising it critically for important intellectual content*: Stella E. Hines, Paul Thurman, Eileen Zhuang, Melissa McDiarmid, Hope Waltenbaugh, and Emily Haas. *Final approval of the version to be published*: All authors. *Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved*: All authors.

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CONFLICT OF INTEREST STATEMENT

Stella E. Hines reports completed research funding to her institution from the Department of Defense and CleanSpace Technology, a respirator manufacturer not associated with the respirators studied in this paper. The remaining authors declare no conflicts of interest.

DISCLOSURE BY AJIM EDITOR OF RECORD

John Meyer declares that he has no conflict of interest in the review and publication decision regarding this article.

DATA AVAILABILITY STATEMENT

Research data are not shared.

INSTITUTION AND ETHICS APPROVAL AND INFORMED CONSENT

The Institutional Review Boards of the University of Maryland Baltimore (HM-HP-00094424-1) and Allegheny-Singer Research Institute (ASRI) West Penn Allegheny Health System (WPAHS) (2021-034) approved this research. This protocol was considered exempt under 45 CFR 46.101(b) from IRB review as research that only includes interactions involving use of survey procedures and the information obtained was recorded by the investigator in such a manner that the identity of the Human Subjects could not be readily ascertained directly or indirectly. Waiver of written informed consent was granted due to the minimal risk posed by survey participation; however, participants reviewed an introduction document before electronic survey completion that detailed the research nature of the survey, voluntary participation status, and contact information for the investigator. N95 is a certification mark of the US Department of Health and Human Services (HHS) registered in the United States and several international jurisdictions.

DISCLAIMER

The findings and conclusions in this report are those of the author(s) and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention.

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ENDNOTE

[1] 45 C.F.R. part 46.101©; 21 C.F.R. part 56.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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