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Planning for Epidemics and Pandemics: Assessing the Potential Impact of Extended Use and Reuse Strategies on Respirator Usage Rates to Support Supply-and-Demand Planning Efforts

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Abstract

During epidemics and pandemics healthcare personnel (HCP) are on the front line of disease containment and mitigation. Personal protective equipment (PPE), such as NIOSH-approved N95 filtering facepiece respirators (FFRs), serve an important role in minimizing HCP risks and are in high demand during public health emergencies. Because PPE demand can exceed supply, various public health strategies have been developed to reduce the rate of PPE consumption as supply dwindles. Extended use and limited reuse of N95 FFRs are strategies advocated by many governmental agencies used to increase the number of times a device can be used. Increased use of respirators designed for reuse—such as powered air-purifying respirators (PAPRs) and elastomeric half-mask and full facepiece air-purifying respirators— is another option designed to reduce the continuous need for new devices as the daily need for respirator use increases. Together, these strategies are designed to reduce the number of PPE units that must be discarded daily and, therefore, extend the longevity of available supply. The purpose of this paper is to theoretically estimate the impact of extended use and limited reuse strategies for N95 FFRs and the increased use of reusable respirator options on PPE consumed. The results suggest that a considerable reduction in PPE consumption would result from extended use and limited reuse of N95 FFRs and the increased use of respirators designed for reuse; however, the practical benefits must be balanced with the risks and economic costs. In addition, extended use and reuse strategies must be accompanied by proper procedures to reduce risk. The study is designed to support epidemic and pandemic PPE supply and demand planning efforts.

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Keywords

COVID-19; N95 respirator; filtering facepiece respirator; pandemic response; crisis capacity; respirator shortage; reuse; extended use

INTRODUCTION

NIOSH-approved N95 filtering facepiece respirators (FFRs) are often recommended for the protection of healthcare personnel (HCP) when providing care to patients infected with airborne transmitted pathogens (Biscotto et al., 2005; Brosseau et al., 2015). During public health emergencies, the supply of N95 FFRs may become strained (Murray et al., 2010; Beckman et al., 2013; Hines et al., 2014; and Srinivasm et al., 2004). Hospitals maintain a limited supply of personal protective equipment (PPE), and rely on strategic stockpiles and the supply chain to provide additional PPE when needed. These sources of PPE, however, may be unable to meet demands during epidemics and pandemics (Yorio et al., 2019; Pyrek, 2014; Abramovich et al., 2017; Carias et al., 2015; Murray et al., 2010; Hashikura and Kizu, 2009; Hick et al., 2009; Swaminathan et al., 2007; Kaji and Lewis, 2006). The COVID-19 pandemic has caused a severe strain on global PPE supplies, including gloves, facemasks, face shields, gowns, and N95 FFRs (WHO, 2020a).

Given these challenges, numerous governmental and non-governmental organizations, including the World Health Organization (WHO, 2020a), the U.S. Centers for Disease Control and Prevention (CDC, 2020a), the U.S. Food and Drug Administration (FDA, 2020), the U.S. Occupational Safety and Health Administration (OSHA, 2020), and the U.S. CDC National Institute for Occupational Safety and Health (NIOSH, 2020), have offered strategies to conserve the limited supply of PPE during the COVID-19 pandemic. Generally, these strategies advocate the use of engineering and administrative procedure approaches for hazard control, while prioritizing the conventional use of PPE for healthcare occupations and tasks with greatest risk (e.g., those that involve aerosol generating procedures, such as bilevel positive airway pressure ventilation, endotracheal intubation, and bronchoscopy). As an epidemic or pandemic intensifies and the supply of PPE depletes, strategies for safe extended use and reuse of PPE (i.e., extended use and limited reuse of N95 respirators and the use of alternative respirators designed for reuse) should be considered. The emphasis on conservation strategies recognizes that the supply of PPE is finite at any given point in time, and the risk of having no personal protection available (after the supply is exhausted) exceeds the risks associated with extended use and reuse.

This overall strategy of progressive PPE conservation during an epidemic or pandemic has been categorized into conventional, contingency, and crisis operational guidelines. Conventional capacity strategies consist of hazard control and PPE use under normal conditions and allow for the full array of engineering and administrative controls with no constraints related to the supply and use of PPE. Under a conventional capacity strategy, PPE such as N95 respirators are typically discarded by HCP after a single close encounter with a patient. Contingency and crisis capacity strategies emphasize strategic components related to both extended use and limited reuse of single use PPE items, and an increased use of reusable respiratory protection devices.

Extended use allows HCP to use a single N95 respirator for repeated close contact encounters with patients without removing the respirator (Fisher and Shaffer, 2014). Like extended use, limited reuse is the practice of using a single N95 FFR across multiple close interactions between HCP and patients, except the FFR is doffed after each interaction and redonned before the subsequent one (Fisher and Shaffer, 2014). Extended use and limited reuse of N95 FFRs and other disposable respirators, however, create risks and should only be considered when there is a substantial risk of depleting the supply to zero. Further, the number of times these devices can be reused is limited. When implemented, these strategies must be accompanied by proper procedures to reduce the risk.[1] Doffing and redonning an FFR can deform components and may impair fit. Bergman et al. (2012) found that most FFR models could be reused (doffed and redonned) up to five times without excessively compromising fit. Given that extended use strategies do not incorporate doffing and redonning, a single device may conceivably be safely used for a greater number of patient interactions (>5) under contingent and crisis operational strategies (Fisher and Shaffer, 2014).

Some respiratory protection devices, such as powered air-purifying respirators (PAPRs) and elastomeric half-mask and full facepiece air-purifying respirators are designed for reuse. If proper attention is given to fit, donning and doffing, cleaning and disinfecting, and filter replacement, these devices can be safely used and reused until replacement is deemed necessary according to HCP or the respiratory protection program administrator. These devices have been extensively used in the manufacturing and industrial construction sectors and recent research has demonstrated that HCP can be assessed rapidly for fit and trained in their use (Pompeii et al., 2020).

Although some of the risks and considerations related to extended use and limited reuse of FFRs have been discussed (e.g., Fisher and Shaffer, 2014; NIOSH, 2020), the supply optimization benefits related to extended use and reuse of FFRs and increased use of reusable options have yet to be examined. The purpose of this paper is to theoretically quantify the potential effects of these strategies on daily respirator consumption. The purpose of this manuscript is not to comprehensively discuss the advantages/disadvantages and risks/benefits associated with extended use, limited reuse, and alternative strategies. As will be discussed, these strategies are advocated by various governmental organizations during times of epidemic or pandemic when PPE supply becomes strained. In order to quantify this effect, a simple simulation was conducted in which the number of interactions between HCP and patients was varied. Baseline daily respirator consumption rates were considered as the instance in which a new respirator was used for each interaction between HCP and a patient. The effect of reuse on the respirator daily consumption (burn) rate was then quantified as: 1) the mean percent reduction in daily consumption compared to the baseline; and 2) the average daily number of respirators that would theoretically be

[1]Please see Fisher and Shaffer, 2014; NIOSH, 2020; and OSHA, 2020 for a thorough discussion of the risks and proper procedures related to extended use and limited reuse of FFRs.

discarded at the hospital, state, national, and global levels under the baseline and reuse assumptions of the analysis.

EFFECTS OF EXTENDED USE AND RESUE ON ESTIMATED DAILY PPE NEEDS

The theoretical percent reduction in daily respirator needs, depending on the number of times it is used, can be computed by a ratio of use/reuse scenarios. To compute the fraction of respirator needs between single use and reuse scenarios, one (representing single use items) can be divided by the planned number of times the respirator will be used under contingency or crisis guidelines for FFRs and when using FFR alternatives, such as PAPRs and/or elastomerics. The following formula depicts the computation:

$$(1/n)x100 = percent\,of\ Respirators\ Needed_{n:1}$$

where n is the number of uses considered in extended or reuse scenarios.

To illustrate, if a single use FFR can be reused 5 times when operating under contingency or crisis strategies, the number of FFRs required would be 20% of that expected in single use contexts. For example, if a healthcare establishment admitted 10 sick patients that required the use of a respirator during each interaction, and assuming that each patient was seen once per hour over a 24-hour period, there would be 240 encounters in which a respirator would be worn and discarded. If PPE were reused 5 times, the number of respirators discarded would be reduced to 48 (240 × 20%).

Table I shows a summary of a simulation that extended this computation to respirator use scenarios ranging from 1 to 1000. The models considered a single interaction between HCP and patient as an event requiring the use of a respirator. Under conventional strategies, the expected number of single use respirators required would equal the number of interactions. Beyond the single use scenario, considered the referent group, the range of extended use and reuse scenarios were categorized as: 2–5 uses to reflect limited reuse scenarios to account for Bergman et al.'s (2012) finding that 5 or fewer donnings sufficiently preserved the fit characteristics of FFRs; 6–10 and 11–20 uses, to reflect possible extended use scenarios; and 21–99 and 100+ uses, to reflect use scenarios associated with PAPRs and elastomerics.

Table I shows the average percent of respirators needed (compared to the referent group) for reuse scenarios. When single respirators are used 2 to 5 times, on average, approximately 32% of the number of respirators used daily are discarded, compared to the single use respirator scenario. Where respirators are used 6–10 times, an average of 13% of the single use discarded volume can be anticipated. Respirators that are used 11–20 times resulted in an average of 6% of the single use volume discarded daily; 21–99 times resulted in an average of 2% of the referent volume; and uses over 100 times resulted in an average of 0.3% of the single use volume.

To further quantify the implications of respirator extended use and reuse on supply, the number of interactions requiring the use of respirators was theoretically estimated at the hospital, state, national, and global levels. The simulation fixed the number of interactions between HCP and a patient to one per hour—resulting in 24 total daily interactions per patient that would require a respirator.[2] Each level of analysis (hospital, state, national, and global) varied according to realistic possibilities of infected patients as observed during the current COVID-19 pandemic (CDC, 2020b; WHO, 2020b). Table I includes the average daily volume of respirators needed according to the use categories denoted. At the national level, the results suggest that 2,400,000 daily interactions may be expected for 100,000 patients, requiring 2,400,000 instances in which a respirator would be needed. If each respirator were used one time (the referent group), the number of respirators discarded would be equal to the number of daily interactions (2,400,000). In the same scenario, if respirators were used for 6 to10 interactions, the daily volume required would be 313,440; ~13% of the volume that would be used under a single use scenario, a reduction of 2,086,560 per day.

Figure 1 depicts the theoretical number of respirators that would be discarded daily at the hospital level considering one interaction per hour between HCP and 10, 50, and 100 patients for each use category. To illustrate, if 50 patients are considered, 1,200 respirators would be discarded daily under the single use scenario. This number would be reduced to an average of 380 (i.e., a difference of 820 respirators) discarded per day, if the number of respirator uses was increased between 2–5 times, and further reduced to 157 (i.e., a difference of 1,043) discarded per day, if the number of respirator uses was increased to 6–10 times. Table I can be consulted for additional scenarios at the levels of analysis considered in the simulation.

LIMITATIONS AND DIRECTIONS FUR FUTURE RESEARCH

It is important to note the theoretical notion of the simulated number of respirators used daily at the hospital, state, national, and global levels. These estimates were based solely on the imputed number of daily interactions between HCP and patients which were fixed at one interaction per hour, per patient. This fixed factor was used only to demonstrate the relative effect of extended use and limited reuse of N95 FFRs and the use of reusable respirator options on expected daily respirator burn rates. In practice, the number of interactions would vary, and future studies designed to more accurately estimate objective burn rate levels of certain PPE may seek a variable rate.

In addition, the current study used respirators as an exemplar regarding the effect of extended use and limited reuse of FFRs and the increased use of reusable options like PAPRs and elastomerics on supply. It should be noted that similar reuse scenarios may be applied to other types of PPE used by HCP—such as protective clothing, face and eye protection, and hand protection (FDA, 2020). Although the equation referenced in this paper would be the same for computing the percent reduction in volume consumed depending on the number of uses, the groupings may be different according to the number of uses. Future

[2]This simulation used 24 daily interactions between HCP and a single patient *only* to theoretically quantify the relative effects of extended use and limited reuse.

studies may be designed to estimate the effect of categories practically relevant to different types of PPE.

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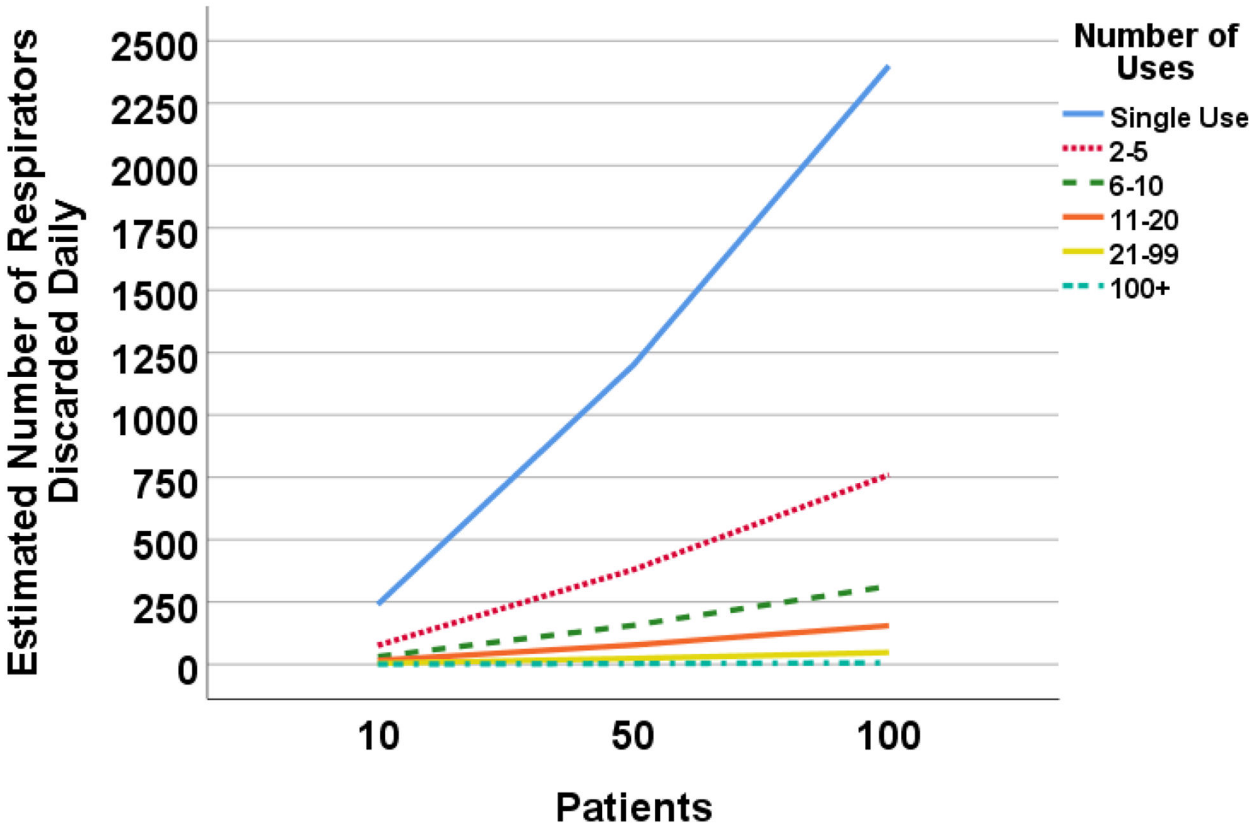

Figure 1.
Simulated effects of N95 extended use and limited reuse strategies, and the integration of respirators designed for reuse, on daily usage rates at the hospital level.

Table I.

Simulated Effects of Respirator Extended Use and Limited Reuse Strategies, and the Integration of Devices Designed for Reuse, on Daily Usage Rates

Theoretical Level of Analysis		**Hospital Level**			**State Level**		
Number of Patients		10	50	100	1,000	5,000	10,000
Number of Interactions between HCP and Patients per day		24	24	24	24	24	24
Total Number of Daily Interactions between HCP and Patients		240	1,200	2,400	24,000	120,000	240,000
Number of Times PPE is Used	**Average Percent of PPE Needed Compared to the Referent Group**	**Average Daily Volume of PPE Needed by Use/Reuse Categories**					
Single Use (1)	Referent group (100%)	240	1,200	2,400	24,000	120,000	240,000
2–5	32%	76	380	760	7,601	38,004	76,008
6–10	13%	31	157	313	3,134	15,672	31,344
11–20	6%	16	78	155	1,550	7,752	15,504
21–99	2%	5	24	48	478	2,388	4,776
100+	0.3%	1	3	6	62	312	624
Theoretical Level of Analysis		**National Level**			**Global Level**		
Number of Patients		75,000	100,000	125,000	500,000	550,000	600,000
Number of Interactions between HCP and Patients per day		24	24	24	24	24	24
Total Number of Daily Interactions between HCP and Patients		1,800,000	2,400,000	3,000,000	12,000,000	13,200,000	14,400,000
Number of Times PPE is Used	**Average Percent of PPE Needed Compared to the Referent Group**	**Average Daily Volume of PPE Needed by Use/Reuse Categories**					
Single Use (1)	Referent group (100%)	1,800,000	2,400,000	3,000,000	12,000,000	13,200,000	14,400,000
2–5	32%	570,060	760,080	950,100	3,800,400	4,180,440	4,560,480
6–10	13%	235,080	313,440	391,800	1,567,200	1,723,920	1,880,640
11–20	6%	116,280	155,040	193,800	775,200	852,720	930,240
21–99	2%	35,820	47,760	59,700	238,800	262,680	286,560
100+	0.3%	4,680	6,240	7,800	31,200	34,320	37,440

NOTE: The estimates of use at the hospital, state, national, and global levels are theoretical and only meant to be used to demonstrate the possible effects of extended use and limited reuse strategies for N95 respirators, and the integration of respirators designed for reuse, on daily burn rates. Use of N95s under conventional strategy guidance is considered the referent group. A limited reuse scenario of 2–5 uses was included to account for Bergman et al.'s (2012) finding that 5 or fewer donnings sufficiently preserved the fit characteristics of FFRs. Additional use categories (e.g., those that spanned 6–10 and 11–20 interactions) were used to account for extended use possibilities. Groupings with larger numbers of use scenarios (21–99 and 100+) were included to account for respirators designed for reuse, such as powered air purifying respirators and elastomerics.