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Safe and effective re-use policy for high-efficiency filtering facepiece respirators (FFRs): Experience of one hospital during the Covid-19 pandemic in 2020

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A B S T R A C T

The high transmissibility rate of the Severe Acute Respiratory Syndrome Coronavirus 2 facilitated an exponential growth in the number of infections, posing a tremendous threat to healthcare systems across the world. The use of Non-oil 95% efficiency (N95) respirators demonstrated to reduce the risk of virus transmission. The escalated demand in N95 respirators during 2020 generated a massive shortage worldwide which resulted in serious implications, one being an increase in healthcare providers’ costs. In response, various optimization strategies were implemented. This study aimed to assess the implementation of a safe and effective re-use policy for high-efficiency filtering facepiece respirators (FFRs) in a high-complexity university hospital in 2020. Associated costs were estimated through a descriptive accounting analysis of resources saved. Acceptability, appropriateness, and feasibility rates were 80.5%, 78.8%, and 83.6%, respectively. With an implementation cost of approximately 10,000 USD, there was a 56.1% reduction in FFRs consumption, compared with a non-policy scenario, with savings exceeding 500,000 USD in 2020. In a pandemic scenario where it is vital to spare resources, a FFRs rational use policy demonstrated to be a highly cost-efficient alternative in order to save resources without increasing contagion risk among healthcare workers.

Introduction

The 2019 coronavirus disease (COVID-19), caused by Severe Acute Respiratory Syndrome coronavirus 2 (SARS-CoV-2), was declared a pandemic in early 2020. By October 31, 2022, more than 6.5 million people had died of the disease worldwide [1]. The high transmissibility of this pathogen enabled exponential growth in the number of infections, posing a tremendous threat for health systems in the world [2–5].

Non-oil 95% efficiency (N95) respirators, also known as high-efficiency filtering facepiece respirators (FFRs), were approved by U.S. National Institute for Occupational Safety and Health, and widely used since the beginning of the pandemic as part of the personal and protective equipment (PPE) against SARS-CoV-2 [6]. The use of FFRs demonstrated to reduce the risk of virus transmission, especially in aerosol-generating procedures [7]. However, the escalated demand in FFRs during 2020 generated a massive shortage worldwide which resulted in serious implications [8,9].

In Italy, an insufficient quantity of PPE was the unfortunate cause of contagion and deaths of thousands of healthcare workers. In less than three months, after the first case was confirmed, more than 8% of healthcare personnel were infected with SARS-CoV-2 [10]. In low and middle-income countries, the situation was especially dire. For instance, by December 31, 2020, approximately 16.7% of health workers in Colombia had been infected [11].

The escalated demand for PPE likewise markedly increased healthcare providers’ costs. In the United Kingdom, billions of PPE units were purchased with increases in value per unit of up to 1277%, elevating costs by 10,000 million sterling pounds compared to prices in 2019 [12]. In the United States, there was also an increase in such costs of up to 2000% [13]. This market competition left small health facilities and middle and low-income countries’ health centers with the low ability to acquire PPE, as they were forced to buy fewer units at very high prices [14].

In response, various PPE optimization strategies were implemented. For FFRs, strategies included extended use, reuse by rotation, and reuse after disinfection [15–19]. The former strategy was based on the concept that extended use conferred greater protection compared to not using a respirator due to a residual filtration effect. The second approach con-
sidered the virus's capacity of vanishing from surfaces over time, and
the latter was based on the ability of physical and chemical methods to
destroy the virus [16]. Ethylene oxide, heat at different temperatures and
humidity, vaporized hydrogen peroxide, and ultraviolet germicidal
irradiation (UVGI), all have proven to eliminate SARS-CoV-2 [17–19].
UVGI has the advantage of effectively eradicating various pathogens
[20–25] without compromising the fit, appearance, odor, or filtration
capacity of these respirators after more than three disinfection cycles
[18,26].

This study highlights the importance of deploying PPE rational use
strategies in a hospital-setting, in order to avoid resource shortages, and
reduce overall costs while protecting healthcare workers at risk of con-
tagion in the midst of a pandemic without vaccines for protection. The
aim of this study was to assess the implementation of a safe and effective
re-use policy for high-efficiency FFRs, and estimate potential savings in
a high-complexity university hospital such as Fundación Valle del Lili
(Cali, Colombia), during the COVID-19 pandemic in 2020.

Methodology

Fundación Valle del Lili is divided into one main hospital and four
outpatient centers within the city. It comprises of 625 hospital beds, 114
intensive care unit beds, 695 physicians, and more than 5300 employees
with potential exposure to SARS-CoV-2.

An implementation strategy consisting of four phases was developed
within the framework of effective replicable FFR re-use and disinfection
programs. These phases were included in order to achieve the successful
adoption, implementation, and sustainability of an institutional respira-
tor reuse policy. In addition, an accounting analysis of cost savings was
performed.

Evaluation phase

This phase consisted of the evaluation of conditions before policy
implementation, including the identification of PPE demand in health-
care workers exposed to COVID-19, and the supply barriers encountered
during the pandemic.

Pre-implementation phase

An interdisciplinary group was established to evaluate scientific ev-
dence regarding the rational use of the PPE policy, which comprised
guidelines on the use of FFRs according to the degree of SARS-CoV-2
exposure, and their re-use through decontamination using UVGI. FFR-
use indications were defined by the institution’s Infections Committee
(See Table 1).

A strict follow-up on the number of FFRs used monthly at the insti-
tution was carried out.

The average cost of each respirator varied greatly during 2020 due to
market conditions and the negotiation capacity of each buyer. However,
assuming an average price of 2.40 USD, a conservative calculation of
savings was performed.

When the PPE policy protocol was implemented at the beginning of
the COVID-19 pandemic, access to FFRs and regular replacements was
strictly limited to healthcare workers at higher risk of exposure, while
those at lower risk of exposure continued to use conventional surgical
facemasks. Conversely, due to FFR scarcity generated by the increasing
worldwide demand, respirator replacement time for low risk personnel
was considerably longer than for workers at higher risk (Table 1). How-
ever, with the rapid spread of infection, FFR access was extended to
any health professional in close contact with patients, as they were all
considered at risk of infection.

The need to establish a FFR reuse policy to ensure the safety of all
personnel was evident. Thus, the design, piloting, and implementation of
a proper disinfection system for FFR was carried out. Here four meth-
ods were evaluated: autoclave (heat and humidity system), vaporized
hydrogen peroxide, steam using microwaves and UVGI.

After the first disinfection trial, the use of autoclave, vaporized hy-
drogen peroxide, and steam using microwaves, were excluded from the
study due to inefficiency and high costs. When evaluating autoclave dis-
infection, although up to 100 respirators could be decontaminated at a
time, it was proved to be time-consuming and expensive as well. Each
cycle using an autoclave had a duration of about 120 min and direct
costs of approximately 100 USD. Indirect costs of possibly greater value
due to the need of staff to operate the disinfection equipment were like-
wise included.

Disinfection with vaporized hydrogen peroxide was also assessed, re-
sulting in even higher costs than disinfection with autoclaves (217 USD
per disinfection cycle of 10 respirators). Lastly, steam using microwaves
damaged 40% of the respirator after a first disinfection cycle, with de-
tachment and total burn of the nasal metal piece.

UVGI was the only method included in the study in the pre-
implementation phase. UVGI uses disinfection chambers equipped with
UVC light-emitting bulbs at 1.3 J/cm², potency described effective in
eliminating SARS-CoV-2 [27]. In this scenario UVGI showed 1) preser-
vation characteristics: unaltered shape and filtration capacity after mul-
tiple cycles; 2) cost-efficiency by disinfecting up to 8 respirators in 3 min,
no need for additional personnel to operate the machine and low main-
tenance costs (approximately 10 USD per month); 3) practicality while
being used; and 4) safety, since the UV light automatically turns off
when the hatch is opened.

Implementation phase

With these findings, a progressive plan for the installation of disinfec-
tion UVGI chambers was executed, beginning in specific areas to meet
the site and personnel needs. A respirator disinfection protocol was de-

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**Table 1** Chronology of indications for the use of FFR.

| Date           | Indication for FFR                                                                 | Use and replacement                      |
|----------------|------------------------------------------------------------------------------------|------------------------------------------|
| April 6, 2020  | Healthcare workers in respiratory areas                                            | One for each confirmed COVID-19 patient   |
|                | Surgical personnel in symptomatic or suspected COVID-19 patient case               | One per procedure                        |
|                | In AGP §                                                                           | One per procedure                        |
|                | Some health professionals §                                                         | One every 15 days                        |
| July 28, 2020  | People who during their workday do not manage to maintain a physical distance of   | Two, used every other day and replaced   |
|                | more than two meters                                                               | replaced every 15 days                   |
|                | All health workers and staff during the care of any patient                        | Two, used every other day and replaced   |
|                | All administrative staff with public contact                                       | replaced every 15 days                   |
|                | Staff in respiratory areas and emergency room                                      | One for each shift                       |
| August 28, 2020| Indication for disinfection with UV chamber No change in indication                | No changes in use or replacement         |

§ AGP: aerosol generating procedures.

1 Anesthesiologists, dentists, otorhinolaryngologists, pulmonologists, speech therapists, pulmonary rehabilitation staff, ophthalmologists, head and neck surgeons, endoscopy personnel, respiratory therapists with manipulation of the airway of patients must wear an FFR and obtain a replacement every 15 days.
developed and widely diffused in the institution through virtual platforms and flyers placed above the disinfection chambers. Moreover, during the first weeks of the protocol implementation, training was provided between staff shift changes in order to guarantee proper use of the UVGI chamber.

In a period of 16 weeks, from July 22 to November 10, 2020, 19 UVGI disinfection chambers were installed, 12 in the main hospital, and the remaining 7 distributed among the outpatient centers.

To evaluate the results of the implemented disinfection policy, three metrics were defined: difference in consumption of FFR units, total expenditure, and user satisfaction. The first two metrics evaluated financial impact; a before and after policy implementation analysis was performed.

An average of 18 FFR units per person per month was estimated in the scenario without the policy implementation. This was determined considering 216 working hours per month divided by 12-hour shifts, and a workload of 18 shifts of 12 h each per month.

Risk classification of health workers was based on the Ministry of Labor’s framework of the General System of Occupational Risks, which divided exposed workers to SARS-CoV-2 accordingly into three groups: direct, intermediate, and indirect [28].

Healthcare workers in direct contact with suspected or confirmed SARS-CoV-2 cases were classified as workers at direct risk of exposure. Personnel who may have had contact or exposure to a person suspected or confirmed with SARS-CoV-2 were considered workers at intermediate risk of exposure. Workers with incidental exposure to suspected SARS-CoV-2 cases, given that exposure to the biological risk factor was unrelated to their functions, were classified as workers with indirect risk of exposure. For analytical purposes, mandatory FFR use was determined for personnel with direct and intermediate risk of exposure.

**Maintenance phase**

The FFR reuse policy was advertised through continuous awareness campaigns in order to promote the correct use of disinfection chambers to all the hospital’s healthcare and administrative personnel.

Policy implementation success was measured through surveys that evaluated the acceptability of the disinfection process including: acceptability of intervention measure, perception of the appropriateness of the intervention, and feasibility of the disinfection method chosen. Each survey had four statements that were validated and translated into Spanish [29]. For analytical purposes, responses were divided into three groups: completely agree/agree, neither agree nor disagree, and completely disagree/disagree.

The condition of each FFR after disinfection was measured using an inspection survey sent to all personnel through institutional e-mail (electronic forms were provided on the Microsoft Forms platform). The survey aimed to evaluate the respirator’s physical damage, general appearance, seals, odor, and nasal clip condition post-disinfection.

**Results**

Table 2 shows the number of people at risk of contagion in the institution according to the degree of exposure. On average, a total of 948 people had direct exposure, 2417 intermediate, and 1503 indirect, in any given month. The increase in direct and intermediate risk of exposure personnel stood out, with a positive month-on-month variation in all months except for September. It is important to note that the increase in exposed personnel in the months of October and November coincide with the opening of a new hospital site with more than 800 employees.

![Fig. 1. Expected vs observed FFR consumption in 2020.](image)

**Discussion**

This study assessed the implementation, results, and monetary savings of a strategy to rationalize the use of FFR, in a high-complexity institution during the COVID-19 Pandemic before vaccines were available. The policy was based on two pillars: a rigorous assessment of workers using FFRs, and the implementation of a disinfection system with low costs and high acceptance. The decision to use UVGI over other methods was based on the results of the pre-implementation phase. UVGI showed to be practical and efficient, conserving both the respirator’s physical characteristics and functionality after multiple cycles, while maintaining low operating costs. These findings are consistent with the literature [17–26].

Overall, UVGI was highly accepted as a disinfection method and considered to be an appropriate and feasible intervention among users. However, downsides included the perception of bad odor and the presence of fibers after multiple disinfection cycles and the reuse of the FFR. Still, we considered it unlikely that adherence to its use was significantly affected by these factors due to the good acceptance and credibility of this disinfection method by personnel.

The evaluation of the respirator rational use policy implementation resulted from a time series difference between expected and ob-
served FFR consumption. With an implementation cost of approximately 10,000 USD, a total of 211,581 respirator units were saved, reducing potential FFR consumption in 56.1%, and generating savings of more than 500,000 USD per year for a hospital of approximately 4000 employees at risk.

The literature review conducted by Rowan and Laffey [30] described the reuse and decontamination of PPE in different health centers due to the scarcity of this equipment. To our knowledge, however, our study is the first to assess the cost savings associated with an optimization and disinfection strategy for PPE.

Although the measurement of the effect of the policy on the COVID-19 infection rate in users was outside the scope of the study, the prevalence of SARS-CoV-2 infection in the institution in 2020 was 8.1% among physicians, 8.3% in other health professionals, and 15.1% in administrative personnel. No published data for other hospitals in the country were found for comparison. The closest possible comparison is with the inhabitants of the same city. The preliminary results of a national study of the seroprevalence of COVID-19 show that by November 2020, the prevalence of infection in Cali was 30% [31].

In the context of an emerging pandemic with an unknown virus and no specific treatments nor vaccines available, the adequate use of PPE (including FFR) was key to tackling COVID-19, especially as it lowered transmission coming from hospital personnel.

Limitations to the present study included the lack of data on virus eradication from FFR. Additionally, selection bias might have occurred with survey respondents since they were voluntary and completed online.

**Conclusion**

The policy developed and implemented by this hospital was deemed to be a success. It showed the importance of implementing programs that work hand by hand with health workers, taking into account not only their needs but opinions in order to effectively address public health matters. This strategy demonstrated to be easily implemented, appropriate, and feasible. Respirator’s reuse resulted in important cost-savings, without sacrificing FFR’s filtration properties. Respirator scarcity was properly tackled, allowing hospital operations to continue while allocating economic resources to other needs, all in the midst of the pandemic.

### Table 2
Total personnel exposed to SARS-CoV-2 according to the risk of exposure.

| risk of exposure     | May  | Jun  | Jul  | Aug  | Sep  | Oct  | Nov  | Dec  |
|----------------------|------|------|------|------|------|------|------|------|
| Indirect             | 1802 | 1439 | 1434 | 1456 | 1456 | 1710 | 1347 | 1379 |
| Direct               | 786  | 963  | 1065 | 1172 | 1172 | 868  | 747  | 811  |
| Intermediate         | 1857 | 2164 | 2073 | 2011 | 2011 | 2693 | 3248 | 3280 |
| Total                | 4445 | 4566 | 4572 | 4639 | 4639 | 5271 | 5342 | 5470 |
| Direct + intermediate| 2643 | 3127 | 3138 | 3183 | 3183 | 3561 | 3995 | 4091 |
| Variation%           | 18.3%| 0.4% | 1.4% | 0.0% | 11.9%| 12.2%| 2.4% |

### Table 3
Survey results evaluating the policy implementation success (N = 224).

| Acceptance measure (AIM) | Completely agree/Agree | Neither agree nor disagree | Completely Disagree/ disagree |
|--------------------------|------------------------|----------------------------|-------------------------------|
| The disinfection process of FFR meets my approval | 79.0% | 9.4% | 11.6% |
| The FFR disinfection process is appealing to me | 81.7% | 8.0% | 10.3% |
| I like the disinfection process | 74.1% | 12.9% | 12.9% |
| I welcome the process of disinfection of FFR by UV light | 86.2% | 6.7% | 7.1% |
| TOTAL | 80.2% | 9.3% | 10.5% |
| Intervention appropriateness measure (IAM survey) | | | |
| The disinfection of FFR by UV light seems fitting | 79.9% | 12.5% | 7.6% |
| This disinfection process seems suitable | 79.5% | 10.3% | 7.6% |
| This disinfection process seems applicable | 80.8% | 9.4% | 9.8% |
| This disinfection process seems like a good match | 75.4% | 14.3% | 10.3% |
| TOTAL  | 78.9% | 11.6% | 9.5% |
| Feasibility of intervention measure (FIM survey) | | | |
| The disinfection of FFR by UV light seems implementable | 78.6% | 14.3% | 7.1% |
| Instructions about the disinfection of FFR by UV light seem possible | 84.8% | 9.8% | 5.4% |
| The disinfection of FFR by UV light seems double | 89.3% | 8.5% | 2.2% |
| The disinfection of FFR by UV light seems easy to use | 81.7% | 10.3% | 7.6% |
| TOTAL  | 83.6% | 10.7% | 5.6% |

AIM: Acceptability of Intervention Measure.
IAM: Intervention Appropriateness Measure.
FIM: Feasibility of Intervention Measure.

### Table 4
General inspection survey results (N = 351).

| RESPIRATOR’S CHARACTERISTICS | SCORE | % of responses |
|------------------------------|-------|---------------|
| Disinfection process         | 5 (Very easy) | 68.9 |
|                              | 4 (Easy)     | 19.1 |
|                              | 3 (Neutral)  | 6.8 |
|                              | 2 (Difficult)| 3.1 |
|                              | 1 (Very difficult) | 1.7 |
| General condition            | Optimal      | 76.4 |
|                              | Deformed     | 13.7 |
|                              | They do not fit | 6.7 |
|                              | Detached     | 3.4 |
| Sealed                       | Normal       | 91.7 |
|                              | Does not seal | 8.3 |
| Nasal clip                   | Normal       | 85.2 |
|                              | Worn out     | 11.4 |
|                              | Detached     | 3.4 |
| Odor (bad)                   | Mild         | 30.2 |
|                              | Moderate     | 24.5 |
|                              | Intense      | 24.2 |
|                              | None         | 21.1 |
| Wear                         | With fibers  | 35.0 |
|                              | Rough        | 7.7 |
|                              | Burned       | 4.8 |
|                              | Deformed     | 1.7 |
|                              | None         | 50.8 |
Therefore, in a pandemic scenario where it is key to spare resources in scarcity and financial crisis, policies on the rational use of PPE are promising in assuring protection to hospital personnel, and in turn providing adequate health care services while saving resources.

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None declared.

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Not required.

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