Ultraviolet-C for mask disinfection

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Change in the title since the subject is more specific

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1. Introduction

The typical chemical methods used to sterilize SUPPE are Vaporized Hydrogen Peroxide (VH_2O_2) and Ethylene Oxide (EtO), and the first has been gaining the second's market. Even though VH_2O_2 is ineffective on cellulose-based SUPPE, it is environmentally friendly, and EtO is carcinogenic [1][2][3][4]. The chemical methods have some cons, such as their residues causing allergic reactions and having an intense odor. They depend on specific machinery, and VH_2O_2 is highly unstable when vaporized, losing significant efficiency when condensed [5][6][7][8][3][4][9].

Regarding radioactive sterilization methods, the most common one uses gamma irradiation, and it is already primarily used for sterilizing medical tools on a large scale, but it is highly dependent on expensive machinery, it might cause irreversible deformities on SUPPE, and these methods use radioactive raw material [1][2][10][4][11].

Regarding the energetic methods, the water and the food industry already apply germicidal ultraviolet (UVGI) [1]. Ultraviolet C (UV-C), among the UVGI, can damage biological structures via the photodimerization process since both RNA and DNA bases strongly absorb UV-C [5]. UV-C is suitable due to its low cost, high throughput, ease of use, and no chemical residues left [12][3][13]. UV-C has some limitations related to SUPPE thermal deformation, shadowing, and absorption effects [14][6][2][15][9].

Considering this panorama, UV-C seems to be the method that is more suitable to tackle the problems (economic, environmental, and social) of selecting a sterilization method for SUPPE.

Among different SUPPE, masks and filtering facepiece respirators (FFRs) became necessary due to their primary role as a protective barrier from Coronavirus disease infection in the hospital and nonhospital environments [16]; therefore, this paper focuses on these SUPPE. This analysis allows observing if studies benefit from advantages and face the disadvantages described for UV-C and how they are overcoming them. Such evaluations are essential because UV-C is already useful in disinfecting other materials/equipment/products, but there remain doubts concerning its disinfection ability for masks/FFRs.

2. UV-C's Germicidal Capability

UV-C (200-280 nm), among the UVGI, damages biological structures via the photodimerization process [17]. At this wavelength, microorganisms' nucleic acids (DNA and RNA) undergo chemical reactions that inactivate them [18], as their DNA and RNA are responsible for cellular replication and protein synthesis [19]. Since UV-C prevents essential microorganism activity, it turns into an appropriate method for disinfecting surfaces, in general.

Considering the studies in the SLR's final database, 31 studies [20][12][21][22][23][24][25][26][27][28][29][30][31][32][33][34][35][36][37][38][39][40][41][42][43][44][45][46][47][48][49], representing 53.45% of the SLR database, attest to UV-C's germicidal capability, as they find results of at least 3-log reduction using different biological indicators, conditions, and setups. These studies present results using UV-C as a single method of sterilization. In contrast, another five studies [31][50][51][48][52] use ultraviolet in hybrid models, four combined heat and UV-C, and one adds hydrogen peroxide. While two publications [50][52] do not evaluate UVGI alone, the other two [31][51] do, one attesting for it and another one not. The last one [48] simulates its efficiency. However, when the authors evaluate the hybrid model, they find reductions "well beyond 3" -log [51] (p. 13). Additionally, four research papers [20][34][38][39] indicate a relation between virucidal activity and the masks' (or FFRs') models. Summing these results up, all of the researchers tested for the germicidal capability of UVGI and found at least partial confirmation of it, being the majority working with UV-C and being in favor of its usage.

Besides its need to be germicidal for SUPPE, UV-C must have low cost, high throughput, ease of use, and reduce or leave behind no chemical byproducts [12][3][13]. The sum of these advantages creates appeal for this reprocessing method. These advantages can be either read solely for UVGI methods or in comparison with other (thermal, chemical, and radioactive) methods' disadvantages.

3. UV-C's Additional Advantages

Ultraviolet-C is normally regarded as a low-cost reprocessing method. From the SLR's final sample, most publications used either adapted biosafety [12][35][36][40][41][42][44][53] or sterilization [16][39][54] cabinets; adapted chambers [7][26][30][50][46][48][55][56], rooms [51][57][58][49] or laminar flow cabinets [30][59][60][61]; the lamps alone [25][27][33][37][62][45][63][64] or tube racks [65]. Most of these resources are available in research departments or hospitals; making this method "reasonably (…) inexpensive" [7] (p. 515) or, at least, "a cost-effective alternative to heat or chemical decontamination" [58] (pp. 396–397).

Ten publications [21][24][29][31][32][43][66][67][68][69] adapted machines/robots or used specific UVGI cabinets. These options seemed more expensive approaches than the previous ones. This information does not completely invalidate the "low-cost" idea, as they might prove to be cost-effective once the facility is looking for reprocessing masks and might already own such devices, and they may be idle. Lastly, some researchers created prototypes [28][70], or built their own UV cabinets [20][22][38][47][71][72][52][73]. These self-built UV cabinets are sometimes built from scratch using inexpensive raw materials like aluminum [20][47], or they adapted other containers [38][71][72][52], such as metallic tool storage, an old freezer box, or a reflecting box.

Considering that UVGI methods are of high throughput, this advantage is not mentioned by every study. Assuming that most studies use small chambers [7][26][30][50][46][48][55][56], biosafety [12][36][40][41][42][44][53] or sterilization [16][39][54] cabinets, this could partially hinder this advantage, as SUPPE cannot be stacked (piled up) [34][68].

Although some publications [7][28][40] argue that reaching high throughput depends on adapting their systems' setups, which increases their processes' agility and consequently their throughput per round, finally, some studies [26][31][71][72][67] indicate an actual number of masks and FFRs disinfected per round. These numbers depend on the area each mask model has and the irradiated area the system has. Despite these studies, this capability becomes easily observed when researchers use adapted rooms [51][57][58][49] since they can disinfect multiple SUPPE at once.

In the matter of effortlessness application of UVGI, fewer studies [7][21][28][31][50][38][72][67][64] discuss it. Usually, this characteristic relates to how easy the insertion of these setups into the potential users' facilities is or how workers benefit from it amidst each patient consultation. On some level, this effortlessness of inserting these setups into healthcare facilities is more important than workers' ability to know how to do it. We argue that possible users should invest in training a group of workers and detach them for this job, given that if every worker starts doing it, it will increase the probability of someone not following the guidelines correctly, thus increasing the infection probability.

The last common advantage UVGI has compared to chemical disinfection methods is the reduced/no chemical byproduct left in SUPPE after sterilization rounds. Some studies [7][27][31][50][35][66][46][71][65][59][63][61][53] discuss this advantage. On the one hand, a few studies [7][27][53] only mention this advantage without testing it—three [65][59][61] publications tangentially discuss this characteristic by the possibility of the lasting odors resulting from the UV-C reprocessing. On the other hand, other publications [31][50][35][66][46][71][63] test for this chemical byproduct. Using low-pressure mercury lamps during the sterilization may create Ozone (O_3), which "can pose an additional health hazard" [46] (p. 7592); if trapped inside the container, the reprocessing is taking place. Three research papers [31][50][46] find low accumulation levels of O_3 ranging from less than 0.001 to 0.02 ppm after the UV-C sterilization process.

Still on chemical byproducts, two other publications [66][63] find some unique peaks in their analysis, but these results indicate divergent observations. Jung et al. explain that the byproducts are a result of "surface oxidation leaving some peaks of C–O–C and O–H bending" [66] (p. 11). In contrast, Salter et al. argue that their unique peaks "appear to be (…) related to the solvent (*n*-pentane) and unrelated to the disinfectant" [63] (p. 443).

Despite these advantages, there is no universal option concerning sterilization methods since all of them present disadvantages; thus, we should observe which disadvantages are present in our SLR database and if they have made this choice of reprocessing procedure inadvisable.

4. UV-C's Disadvantages

There are three common problems the UV-C sterilization process demonstrates: the possibility of thermal deformation, shadowing, and absorption effects [14][6][2][15][9]. As the first potential problem (changes in integrity) already discards reprocessed SUPPE, we opted to leave it on Table 1 column "Changes in integrity or fit." From our SLR database, 30 studies (51.72%) assess it, of which 21 [16][22][24][27][31][50][35][51][70][44][66][46][47][71][65][59][67][60][74][61][64] observe no physical changes within different rounds of sterilization or extenuating conditions. On the other hand, nine studies [23][25][29][34][62][55][56][73][54] find that masks or FFRs degraded, or faced changes in airflow resistance [23][34][55][56], or reached minimum acceptability levels after some rounds of reprocessing [25][29][62][73][54]. These results are important to consider, albeit with caution because one publication [56] indicates that despite having degradation problems, they varied according to the different models used, suggesting that it is wise to observe each case individually. In contrast, another study [55] indicates a positive relationship between degradation levels and dosage.

Another potential problem reprocessed masks and FFRs might present the reduction of their filtration power. Most studies [22][23][25][26][29][30][31][50][35][51][62][42][44][66][46][71][67][68][60][74][61][73][64] indicate that little or no effect happened as these SUPPE faced UV-C sterilization. However, this is not a consensus in the SLR's final sample. Few publications [7][16][55][69] indicate problems in these SUPPE's filtration power after sterilization, normally after some reprocessing cycles or in higher doses.

A third setback for choosing UV-C's method is shadowing. This problem happens when parts of the masks or FFRs are poorly irradiated or not irradiated at all. Such a concern is a priority, especially when the object possesses inner-layers where microorganisms can remain. This problem automatically impacts UV-C's germicidal capability because all parts must be irradiated to be decontaminated and reused. Shadowing is also a problem in these SUPPE's straps. Some studies [20][24][27][28][31][38][41][48][71][72] discussed shadowing although only few [28][31][38][48][72] presented possible solutions. One study [28] is concerned with this problem regarding masks and FFRs straps, then to solve it, they include a fused quartz hook that enables UV irradiation. Other researchers [31][38][48][72] suggest changing the UV-C system setup or the SUPPE's positions to increase exposure or the system's reflection.

A fourth problem concerns UV-C's penetration ability. This problem is intimately related to the irradiation of inner parts and with the material these SUPPEs use. Some studies [20][12][21][27][68] argue about it. The leading cause for this concern lies in the physio–chemical properties of the materials used in masks and FFRs [12][21][68]. None of these studies discussing absorption problems tried to solve them. Only one [27] argued about the possibility of optimizing their system's setup to cope with it. Nevertheless, an increase in dosage to reach deeper layers may lead to photooxidation on the surface [29][71][55]. Thus, better reflective setups and more uniform irradiation might prove to be better solutions to reach the inner layers.

A fifth problem lies outside the capability of UV-C but in the potential users' ability to explain to the users of reprocessed SUPPE the procedure's safety. Only two studies [29][67] discuss it, but a system where users of the reprocessed masks and FFRs only wear their previously used SUPPE may increase acceptability.

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