Disaster Medicine and Public Health Preparedness

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Concepts in Disaster Medicine

Cite this article: Vaupel F, Fengler I, Mutters NT, *et al*. Investigation of three different UV-C irradiation schemes for bacterial decontamination of FFP2 masks to make them reusable. *Disaster Med Public Health Prep*. **18**(e91), 1–7. doi: https://doi.org/10.1017/dmp.2024.86.

Keywords:
capacity building; decontamination; occupational exposure; pandemics; protective devices

Abbreviations:
CFU, Colony Forming Units; COVID-19, coronavirus disease; DIN, Deutsches Institut für Normung e.V.; DNA, deoxyribonucleic acid; FFP, filtering face piece; IQR, interquartile range; MALDI-TOF MS, matrix-assisted laser desorption/ionization time-of-flight mass, spectrometry; PPE, personal protective equipment; SARS-CoV-2, severe acute respiratory syndrome coronavirus 2; SUDS, Synchronous UV Decontamination System; UV-C, ultraviolet radiation in the wavelength range between 100 nm and 280 nm; WHO, World Health Organization

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Investigation of Three Different UV-C Irradiation Schemes for Bacterial Decontamination of FFP2 Masks to Make Them Reusable

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Abstract

The effect of filtering face piece grade 2 (FFP2) masks for infection prevention is essential in health care systems; however, it depends on supply chains. Efficient methods to reprocess FFP2 masks may be needed in disasters. Therefore, different UV-C irradiation schemes for bacterial decontamination of used FFP2 masks were investigated.

Seventy-eight masks were irradiated with UV light for durations between 3 and 120 seconds and subsequently analyzed for the presence of viable bacteria on the inside. Ten masks served as the control group. Irradiation on the inside of the masks reduced bacteria in proportion to the dose, with an almost complete decontamination after 30 seconds. Outside irradiation reduced the quantity of colonies without time-dependent effects. Both sides of irradiation for a cumulated 30 seconds or more showed almost complete decontamination.

Overall, this study suggests that standardized UV irradiation schemes with treatment to both sides might be an efficient and effective method for FFP2 mask decontamination in times of insufficient supplies.

Filtering face piece (FFP) masks are an essential part of personal protective equipment (PPE) for the transmission prevention of air transmitted bacteria or viruses both in the medical and public sectors. Increased demand leads to increased dependence on supply chains.[1] Therefore, disruption in production, shipment, or delivery may result in mask shortages with severe consequences for individual health and public health. Incidences like the coronavirus pandemic in 2019,[2] the accident of the "Ever Given,"[3] the war in Ukraine,[4] and the earthquakes in Turkey and Syria in 2023[5] clearly demonstrated the fragility of this supply chain system. Especially, mask shortages during the coronavirus disease (COVID-19) pandemic emphasized the importance of the supply-chain-independent provision of FFP2 masks. In March 2020, the World Health Organization (WHO) warned of danger to health care workers due to shortages of personal protective equipment such as FFP2 masks[2] while patients with COVID-19 had to be treated by doctors and nursing staff without masks.[6] It must be assumed that globalization and climate change will make pandemic[7] and supply chain disruptions more common, due to maritime events, for example.[8] This makes it impossible to guarantee a constant and sufficient supply of masks through shipment and delivery.

In order to decrease the dependency on supply chains and be better prepared in the event of a crisis or disaster, it is expedient to develop reprocessing concepts for FFP2 masks and to examine their effectiveness. In recent years, various reprocessing methods have been investigated and resulting recommendations were published.[9–11] These included reprocessing via moist and dry heat, gaseous hydrogen peroxide, and steam.[12] The use of ultraviolet (UV) irradiation (especially UV-C) led to ambiguous results in the past.[12]

UV irradiation has been used for many years for the disinfection of water, surfaces, and air.[13] The absorption of UV irradiation induces stable connections between 2 pyrimidine bases in the deoxyribonucleic acid (DNA) of microorganisms such as bacteria, leading to the formation of especially thymine dimers and causing the disruption of the DNA's replication. The microorganism becomes incapable of reproduction or dies.[14] The UV lamps used in this study emitted UV-C light, which is the most energetic part of UV light. It ranges at wavelengths from 100 nm to 280 nm[15] and includes the absorption maximum of nucleic acids at 260 nm.[14]

In this study, effective UV-C irradiation schemes for bacterial decontamination of FFP2 masks were investigated with the aim of reusing worn masks in times of insufficient supplies.

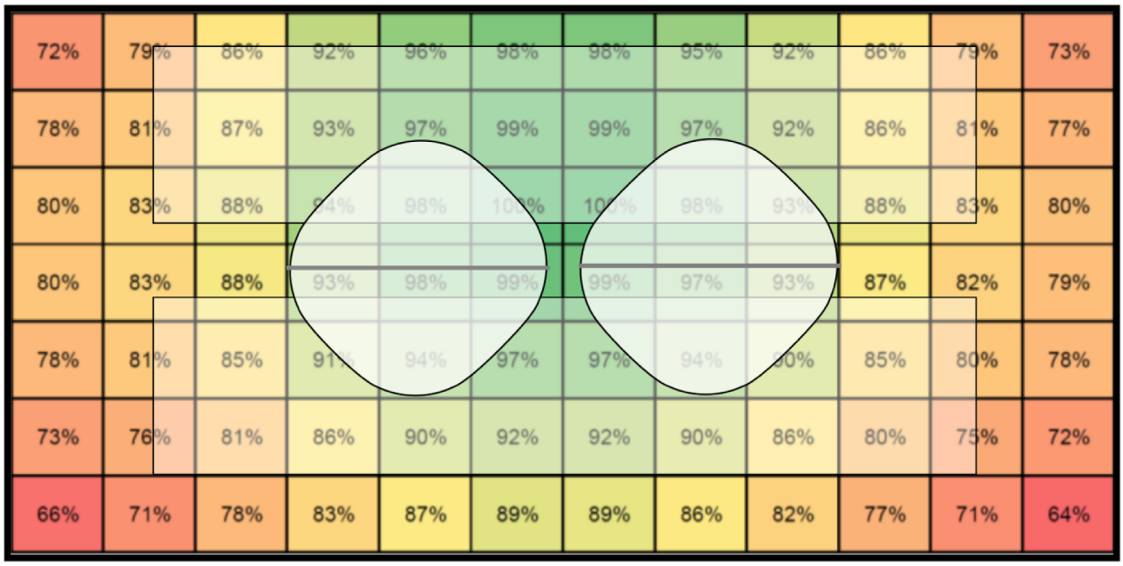

Figure 1. Schematic top-down view of the irradiation chamber with decreases of irradiation efficiency in the different areas.[16] The door of the chamber is on the bottom of the figure. The masks are figured in white; the metallic mask holders are figured in transparent white.

Methods

Acquisition of Used Masks

All masks examined had been worn properly by hospital staff (according to the severe acute respiratory syndrome coronavirus 2 [SARS-CoV-2] pandemic regulations) and were collected randomly throughout the hospital personnel. The mask users were informed verbally about the planned examinations. No personal data were collected, and only the duration of use was documented. Participation was voluntary, and handing over the mask was therefore considered informed consent. Only masks with a duration of use between 1 and 12 hours, that were visually intact and clean, were included in this study. The chosen masks were subsequently packed in sealable plastic bags and transported to the laboratory within a maximum of 8 hours after use. The distribution of the masks among the different UV-C irradiation schemes was also random.

Irradiation

The study used the irradiation chamber BS-02 with the control unit UV-Mat (Opystec Dr Gröbel GmbH, Ettlingen, Germany). It was equipped with 8 UV-C lamps (Philips, TUV 15W G15 T8, Hamburg, Germany). The luminants emitted radiation with a wavelength of approximately 250 nm.[16] The distance between the masks and the UV-C lamps was 15 cm.

The irradiation chamber ran on full power with 10 $\frac{mW}{cm^2}$[17] since no dimming was set. Two masks were irradiated simultaneously per run (Figure 1) with an estimated average energy throughput of 95%. The formula for the calculation of the irradiation dose is shown in Equation 1.

$$Irradiatn\ dose\ per\ side\ \left[\frac{mJ}{cm^2}\right] = 95\% * 10\frac{mW}{cm^2} * duration\ of\ irradiation \quad (1)$$

The UV-C irradiation schemes were

1. Inside irradiation only; masks face-side up in the chamber
2. Outside irradiation only; masks face-side down in the chamber
3. Both sides of irradiation, combined; masks face-side up in the chamber and rotated after half the irradiation time

Bacterial Examination

All masks were examined according to Deutsches Institut für Normung e.V. (DIN) 10113[18] using 25 cm^2 Tryptic Soy Agar plates (RODAC contact plates, Becton Dickson, New Jersey, USA). The incubation period was 48 hours at 37±2 °C. All bacteria that were identified as potentially clinically relevant based on their morphology were sub-cultivated on Columbia Agar (with 5% Sheep Blood, Becton Dickson, New Jersey, USA) and further characterized via Matrix-assisted laser desorption/ionization time-of-flight mass spectrometry (MALDI-TOF MS, MALDI Biotyper, Bruker Daltonics GmbH & Co. KG, Bremen, Germany).

Statistical Analysis

Stata IC 15.1 (StataCorp, College Station, Texas, USA) was used for statistical analysis. The study focused on non-parametric methods for the statistical analysis of the data, as a normal distribution could not be assumed due to the small sample size. The alpha-level was set at 0.05.

The influence of the duration of mask use on bacterial contamination in non-irradiated masks was tested via a linear regression. For irradiated masks, a linear regression was used to test the influence of irradiation time on the bacterial contamination treatment.

The Kruskal–Wallis test was used to detect differences in duration of use or model type between and within the different UV-C irradiation schemes.

Results

Table 1 shows the number of irradiated masks by UV-C irradiation scheme with duration of use and model types. There was no global difference in the duration of use between the different UV-C irradiation schemes ($P = 0.5648$). Within the UV-C irradiation schemes, there was no difference in the duration of use between

https://doi.org/10.1017/dmp.2024.86 Published online by Cambridge University Press

Table 1. Manufacturer, model, EN149 mask type: bluebec, model BB203, FFP2NR; MUSK, MUSK21, FFP2NR; Sentias, DE.W42-A, FFP2NR; Amoedos Healthcare; DMaske, 2a, FFP2NR; Mea Vita, HKN001, FFP2NR; Guangdong YIDAO medical technology, YPHD, KN95

Irradiation scheme	Seconds	n	Duration of use/h [IQR]	Model (n)
Non-irradiation	0	10	4 [1–6]	bluebec (5), MUSK (3), Dmaske (1), Mea Vita (1)
Inside irradiation	3	4	5 [4.5–5.5]	bluebec (4)
	15	4	4.5 [3.75–4.75]	bluebec (2), MUSK (1), Sentias (1)
	30	8	3 [1–4]	bluebec (5), MUSK (2), Sentias (1)
	45	4	5.5 [4.5–6]	bluebec (2), MUSK (2)
	60	8	4 [2.5–5.5]	bluebec (7), MUSK (1)
	90	6	5 [4–7]	bluebec (5), MUSK (1)
	120	8	4 [2.5–6]	bluebec (6), YPHD (1), Amoedos Healthcare (1)
Outside irradiation	30	4	6.5 [3–10]	bluebec (4)
	45	4	4 [3–6.5]	bluebec (3), Sentias (1)
	60	4	2.25 [1.75–2.75]	bluebec (4)
	90	4	7 [4–12]	bluebec (4)
	120	4	2.5 [1–4.5]	bluebec (4)
Both sides of irradiation (inside first)	15 + 15	4	4 [3.5–5.5]	bluebec (4)
	30 + 30	4	3.5 [2.5–8]	bluebec (4)
	45 + 45	4	5 [3–6]	bluebec (4)
	60 + 60	4	9 [6–10.5]	bluebec (4)
Total		88	4 [3–6]	bluebec (71), MUSK (10), Sentias (3), Amoedos Healthcare (1), DMaske (1), Mea Vita (1), YPHD (1)

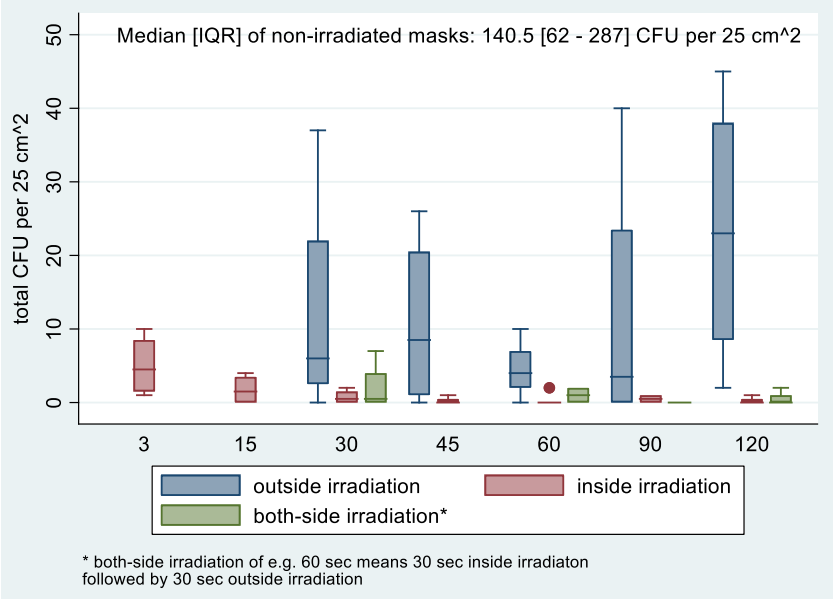

Figure 2. Total CFU/25cm^2 for the different irradiation schemes for different irradiaton durations in seconds. Red: Inside irradiation, time-dependent reduction between 3 and 30 seconds, then stable values between 30 and 120 with a maximum of 2 CFU/25cm^2. Blue: Outside irradiation between 30 and 120 seconds, no time-dependent reduction. Green: both sides of irradiation (inside before outside). Time-dependent reduction between 30 and 60 seconds, then stable values with a maximum of 2 CFU/25cm^2.

the various irradiation times ($P_{\text{inside}} = 0.2536$, $P_{\text{outside}} = 0.1370$, $P_{\text{both sides}} = 0.4944$). There was no global difference in the model types between the different UV-C irradiation schemes ($P = 0.4647$). Within the UV-C irradiation schemes, there was no difference in the model types between the different irradiation times ($P_{\text{inside}} = 0.7228$, $P_{\text{outside}} = 0.4060$, P both sides all masks were identical).

Figure 2 shows the boxplots of the bacterial contamination after different UV-C irradiation schemes. The median bacterial contamination of non-irradiated masks was 140.5 [interquartile range (IQR): 62–287] $\frac{colony\ forming\ units\ (CFU)}{25cm^2}$. The regression showed no significant influence of the duration of use on bacterial contamination in non-irradiated masks ($P = 0.837$, $R^2 = 0.0056$).

Inside Irradiation

For inside irradiated masks, the median bacterial contamination was 0 [IQR: 0–1] $\frac{CFU}{25cm^2}$. There was a time-dependent effect ($P = 0.004$, $R^2 = 0.1927$).

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- After 3 seconds of irradiation time (corresponding to 712.5 $\frac{mJ}{25cm^2}$), the median bacterial contamination was 4.5 [IQR: 1.5–8.5] $\frac{CFU}{25cm^2}$.
- After 15 seconds of irradiation time (corresponding to 3562.5 $\frac{mJ}{25cm^2}$), the median bacterial contamination was 1.5 [IQR: 0–3.5] $\frac{CFU}{25cm^2}$.
- After 30 seconds or more (7125 $\frac{mJ}{25cm^2}$ or more), the maximum bacterial contamination was 2, medians were 0–0.5 $\frac{CFU}{25cm^2}$.

Outside Irradiation

For outside irradiated masks, the median bacterial contamination was 6 [IQR: 1–20.5] $\frac{CFU}{25cm^2}$. There were no time-dependent effects ($P = 0.232$, $R^2 = 0.0782$). The highest bacterial contamination remained after 120 seconds of irradiation time with median 23 [IQR: 8.5–38] $\frac{CFU}{25cm^2}$. The lowest bacterial contamination remained after 60 seconds of irradiation time with median 4 [IQR: 2–7] $\frac{CFU}{25cm^2}$.

Both Sides of Irradiation

For both sides of irradiated masks, the median bacterial contamination was 0 [IQR: 0–1.5] $\frac{CFU}{25cm^2}$. There were no time-dependent effects ($P = 0.186$, $R^2 = 0.1216$). After a cumulated 30 seconds (15 seconds inside, followed by 15 seconds outside) of irradiation, the median bacterial contamination was 0.5 [IQR: 0–4] $\frac{CFU}{25cm^2}$, the maximum bacterial contamination was 7 $\frac{CFU}{25cm^2}$. After a cumulated 120 seconds (60 seconds inside, followed by 60 seconds outside) of irradiation, median bacterial contamination was 0 [IQR: 0–1] $\frac{CFU}{25cm^2}$, the maximum bacterial contamination was 2 $\frac{CFU}{25cm^2}$.

Bacterial Differentiation

No obligate or facultative human pathogens were detected in any of the examined samples. Suspicious colonies were identified as bacteria of the human flora, including *Kocuria rhizophila, Micrococcus sp., Neisseria perflava, Staphylococcus epidermidis,* and *S. saprophyticus*.

Limitations

This study has 4 main limitations. First, the initial contamination of the masks before irradiation was not investigated. The irradiated masks were not bacterially examined before the intervention and therefore the concrete bacterial reduction through UV-C for each mask could not be determined. In this study, the bacterial examination of the 10 masks that served as a control group showed a high variance in bacterial quantity with a median contamination of 140.5 CFU per 25cm^2. Another study showed similar results with a median CFU count of 168 ± 24.7 on the face-side and 36.0 ± 7.0 on the outer-side.[19] The high variance in bacterial quantity on worn masks accentuates the importance of investigating how the initial contamination may influence the irradiation result.

Second, it remains unclear whether the reported UV-C irradiation schemes are applicable for the reprocessing of other mask types as only a representative number of FFP2 masks from the manufacturer Bluebec was included in the study (see Table 1). The irradiation results with the few masks from other manufacturers indicate a low impact of the manufacturer on the results. However, this assumption must be evaluated on a larger scale.

Third, it was not examined whether the reported UV-C irradiation schemes may reduce the filtration power of the reprocessed masks due to any adverse effects on the mask fibers. Most studies indicate that UV-C-irradiation has little or no effect on the mask's particle penetration[20] and it seems that the limiting factor for the maximum number of reprocessing cycles is the integrity of the respirator body.[21] One study indicates that an irradiation dose of 120 $\frac{J}{cm^2}$ could lead to significant changes in the integrity of the body material.[21] This dose is equivalent to the irradiation dose of over 200 reprocessing cycles with the reported UV-C irradiation schemes. It can therefore be assumed that the maximum number of reprocessing cycles is limited not by the reprocessing itself but by the wear and tear of frequent mask use by health care workers. As the material integrity is very dependent on the respirator model, the impact of the reported UV-C irradiation schemes on the particle penetration should be further investigated on different respirator models and for several reprocessing cycles.

Last, only the effectiveness of irradiation on bacteria was investigated. To what extent the results can be transferred to viruses is not certain. In previous studies, the UV-C doses required for the inactivation of various viruses were investigated. The highest recommended dose required to achieve a 3-logarithmus reduction listed in a detailed compilation was 171 $\frac{mJ}{cm^2}$ for John Cunningham polyomavirus.[22] In the presented study, 30 seconds of irradiation translated into a dose of 285 $\frac{mJ}{cm^2}$. It can therefore be assumed that the irradiation duration that was found to be sufficient for the inactivation of bacteria is also sufficient for the inactivation of viruses. A confirmative study with the same standardized study protocols on this question seems appropriate and expedient.

Discussion

This study shows that in times of crisis or insufficient supplies, effective UV-C irradiation schemes can be used for bacterial decontamination of used FFP2 masks to efficiently make them reusable.

All reported UV-C irradiation schemes showed a reducing effect on the bacterial growth after treatment. According to DIN 10113,[18] which defines a residual contamination of 10 $\frac{CFU}{25cm^2}$ as low-grade contamination, an irradiation for 3 seconds per side would be enough to decontaminate FFP2 masks sufficiently. However, because of the high variance of the CFU count at low irradiation durations and the small and unbalanced sample sizes, a contamination of 2 $\frac{CFU}{25cm^2}$ or less was considered as acceptable in this study.

For outside irradiated masks, the lowest effect can be seen with a decrease in bacterial growth from 140 to 6 $\frac{CFU}{25cm^2}$. The irradiation does not sufficiently penetrate the mask to acceptably decontaminate the other side. For inside irradiation, there is a time-dependent effect, with a median bacterial growth of 0 $\frac{CFU}{25cm^2}$ after at least 30 seconds of irradiation. It can be concluded that inside irradiation sufficiently decontaminates the mask on the same side after 30 seconds of irradiation. As the outside irradiation did not penetrate the mask to sufficiently decontaminate the inner side, it can be assumed that inside irradiation does not sufficiently decontaminate the outside of the mask. To effectively decontaminate FFP2 masks on both sides, both sides of irradiation seem necessary. Both sides of irradiated masks show no time-dependent differences in the bacterial growth after cumulative irradiation between 30 and 120 seconds. Furthermore, the differentiation of grown colonies on irradiated masks showed only bacteria that are part of the normal skin microbiome,[23,24] that pose no danger to

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immunocompetent people. Therefore, we deduce that both sides of irradiation of 30 seconds each with a power of 10 $\frac{mW}{cm^2}$ may be a suitable UV-C irradiation scheme for future use.

When comparing the data of this study with literature data, it is striking that other studies indicate a lower necessary UV-C dose for bacterial decontamination. In this study, 30 seconds of irradiation per side (corresponding to 285 $\frac{mJ}{cm^2}$ per side) were sufficient to bacterially decontaminate worn masks successfully. In another study on the inactivation of various antibiotic resistant bacteria, for example, MRSA and E. coli, an irradiation dose of less than 20 $\frac{mJ}{cm^2}$ led at least to a 3-log reduction of bacteria.[25] One reason for the relatively high inactivation doses determined in the present study could be the different layers of the FFP2 mask that have to be penetrated by UV light for complete decontamination.[20] A study by Fisher and Shaffer on the minimum UV-C dose necessary for the decontamination of filtering face piece respirators found a dose of 100 $\frac{mJ}{cm^2}$ to be sufficient for at least a 3-log reduction in a viable virus.[26] This is about one-third of the minimum UV-C dose recommended in this study. A possible explanation could be the irregular surface of the masks. In this study, whole masks were used for the experiment, while Fisher and Shaffer used circular excisions from the masks.[26] It has been proven that UV light dosage varies significantly depending on the positioning of the masks and that shaded zones may require a higher UV dosage.[27]

Moreover, it must be considered whether the duration of mask use or other user-dependent factors had an influence on the outcome of this study. The results show that the duration of use has only a subordinate influence on bacterial contamination before irradiation, whereas other user-dependent factors seem to have a greater influence on bacterial contamination: It has been proven that beards in different lengths or styles correlate with an increased amount of CFU found inside a mask.[28] However, due to the equally distributed median duration of use of the masks between our radiation schemes, it can be assumed that these user-dependent factors are also randomly equally distributed.

While being successful in proving the effectiveness of the presented method, statements about its efficiency, especially its practicability and its suitability for the masses, are more difficult to make. Particularly both sides of irradiation mean a lot of handling and may bear the risk of recontamination because the masks have to be rearranged between inside and outside radiation. To counteract this risk, a standard operation procedure including sufficient hand hygiene and the use of a face mask (as well as UV-C protective eyewear) by the operator is necessary. Additionally, the masks could be packed in special UV-C-permeable foils[29] that do not absorb UV-light during irradiation and therefore have no impact on the irradiation intensity. This could decrease the risk of mask recontamination while rearranging them between inside and outside irradiation or while wrapping the masks up after the completed irradiation. Further research on different package materials could be expedient.

Another factor that influences efficiency is the throughput of the method. The study design allows the simultaneous irradiation of 2 face masks in a net time of 60 seconds. Additional time is required for loading the irradiation chamber, rotating the masks and prior packaging, if necessary, as well as for personal hygiene measures and handling the protective equipment. Assuming a gross expenditure time of 150 seconds per 2 masks, the throughput would be a maximum of 48 face masks per hour per chamber with 1 staff member working continuously. This way, 1.152 masks could be reprocessed every 24 hours in times of shortages. To further enhance the method's efficiency, it could be considered to increase the number of simultaneously irradiated face masks. The maximum number of masks that fit into the chamber is 5. To obtain the same UV-C doses, the net irradiation time would have to be increased due to the variable distribution of the radiation intensity, as shown in Figure 1. Additionally, the risk of recontamination would be increased because with 5 masks inside the chamber, the handling becomes even more difficult. There would also not be enough space to guarantee that the masks do not touch each other while being rearranged.

To conclude, the presented method is not suitable for larger amounts of face masks because of the complex handling that requires 1 staff member to work continuously and the impracticality to increase the number of simultaneously irradiated masks. It is, however, efficient and practicable for a small number of masks.

There are several promising irradiation devices other than the UV-irradiation chamber used in this study, whose practicability has been examined in other studies.[30–32] An irradiation device that is more accessible than the UV-chamber used in this study is the biosafety cabinet. It is a common element in most academic and hospital laboratories and therefore does not have to be purchased specifically for the reprocessing of masks. The downsides to the reprocessing of face masks in a biosafety cabinet are the lack of the device's portability and the long irradiation times, even when the masks are elevated toward the UV-lamps to reach a higher irradiation dose.[30] To reach the UV irradiation dose that was found to be sufficient for the reprocessing of worn masks in the present study, the masks would have to be irradiated for at least 20 minutes per side.[30] Additionally, the biosafety cabinet cannot be used for its original purposes while masks are being irradiated, which could hold up other work processes. Even if this method could be used in the case of need, the method presented in this study is more locally flexible and has a higher throughput than the biosafety cabinet.

A novel device made specifically for the efficient reprocessing of used face masks is the Synchronous UV Decontamination System (SUDS). It is a device for both sides of irradiation of 1 mask at a time with a dose of over 2$\frac{J}{cm^2}$ in about 1 minute.[31,32] With a reprocessing time of about 2.5 minutes for 2 masks, the throughput of the SUDS is comparable to the throughput of the method presented in this study. The small size makes the device even more portable than the UV-C chamber but restricts its possible use for other reprocessing purposes.

In summary, the UV-C irradiation chamber used for the reprocessing method investigated in this study makes it possible to reach a high throughput with a high flexibility in terms of location and type of use. The SUDS could be a promising alternative or addition to the UV irradiation chamber in the implementation of the presented method, while biosafety cabinets have a lower throughput and are less flexible in terms of location of use.

As for the use outside of crisis situations when supply chains are sufficiently intact, the presented method cannot be recommended. The single use of FFP2 masks is more hygienic than reprocessing them and, especially, this method is prone to errors due to all the handling during the work process, for which there are no process control options. Furthermore, the method should not be considered in routine settings due to the lack of product control options: As 1 batch consists of only 2 masks, it is impracticable to carry out a product control process after each irradiation treatment. Errors in the reprocessing process that could possibly lead to inadequately decontaminated masks can therefore hardly be identified. Additionally, in the European Union[33] as well as the United States of America,[34] the reprocessing of disposable

https://doi.org/10.1017/dmp.2024.86 Published online by Cambridge University Press

products is associated with the assumption of producer responsibility. The reprocessor must prove that the functionality and product safety are guaranteed. Full evidence for this guarantee is not given by this work.

Nonetheless, the presented UV-C decontamination method could be an option for the decontamination of face masks in times of crisis or disaster. The irradiation chamber is very portable and can therefore be used flexibly locally: It is transportable by 2 people or by truck or aircraft and needs only electricity and no other resources, compared to reprocessing using steam, for example. It could therefore be of use for mobile medical units or small medical facilities. The method may improve hygiene and prevent infections whenever supply chains are disrupted, for example, in epidemic or pandemic situations, in remote areas with no supply, or during military operations. It can be especially advantageous during disasters like flooding or earthquakes: Areas where an earthquake occurred are often difficult to reach, medical facilities are not accessible, and resources are needed spontaneously and quickly.[35,36] Additionally, natural disasters like earthquakes often have outbreaks of infectious diseases as a consequence, for example, due to overcrowded shelters or limited hygiene.[37] The presented method to make FFP2 masks reusable efficiently could improve the medical conditions in these areas.

The situations in which the presented method could be of use are highly variable as well as unpredictable. To be better prepared for supply chain disruptions and other possible consequences of disasters, it is recommended to create a generally accessible list of where the necessary resources for this method, such as UV-C irradiation chambers, are located. This way, the resources could be quickly transported to wherever needed in the surrounding area. This could be especially advantageous, and it is believed that pandemics and natural disasters will become more common in the future due to climate change and globalization.[7,8]

Conclusion

UV-C irradiation for 30 seconds inside, followed by 30 seconds outside (translating into 7125 $\frac{mJ}{25cm^2}$ per side), is an efficient UV-C irradiation scheme for bacterial decontamination of FFP2 masks to make them reusable. This reprocessing method can be used as a last resort when no new masks are otherwise available because of supply chain disruptions, disasters, or pandemics, for example. It could be advantageous to create a generally accessible list of where the necessary resources are located.

Author contributions. FV carried out the irradiation, prepared the microbiological samples, and wrote the first draft of the manuscript. IF evaluated the microbiological samples and revised the manuscript. NTM planned and supervised the investigations and revised the manuscript. PS provided resources (irradiation chamber, staff for briefing). ES evaluated the microbiological samples. RW provided resources (masks) and created the database and supervised the documentation of the examinations. MD planned and supervised the investigations, analyzed the data, and revised the manuscript.

Funding statement. None.

Competing interests. All authors state that they have no competing interests regarding this study.

Ethical standards. No personal data were collected, processed, or saved for this study. No experiments were conducted on or with humans or animals. The irradiated masks are legally considered waste, which means that there are no longer any property rights. Therefore, IRB approval was not necessary from the authors' points of view.

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