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CHAPTER 15

Addressing the global challenge of access to supplies during COVID-19: mask reuse and local production of alcohol-based hand rub

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15.1 Introduction/background

In light of the current COVID-19 pandemic, many health care facilities worldwide are lacking a steady source of supplies. Access to alcohol-based hand rub (ABHR), and personal protective equipment (PPE), especially masks, is a cornerstone for infection prevention and control (IPC) practices during a pandemic. The pandemic caused major disruptions to the global shipping infrastructure, when coupled with a drastic, almost simultaneous global increase in demand for these products. This emergency situation warrants the taking of extraordinary measures to minimize the negative health impact of a lack of supplies; numerous health care facilities found themselves without enough appropriate equipment to safely take care of their patients. Two areas where new approaches are rising to meet the challenges that COVID-19 has posed for global supply chains are the local production of ABHR and masks, and their decontamination and reuse. The crisis has led to new supply chains and changes to the distribution in manufacturing systems.¹

Many countries have been working together with local industries to make it easier to produce the necessary supplies locally. This includes measures such as capital investment, help with the procurement of raw materials and distribution, as well as help from a legal standpoint. Because medical equipment and alcohol are two types of products that are rather heavily regulated, countries are trying to deregulate these laws and at least

temporarily modify them to allow for a more efficient production during the pandemic.²⁻⁴

Local production for ABHR has already been implemented in a number of places around the globe, following the World Health Organization (WHO) guidelines.⁵ This is usually done in order to help make hand rub more accessible in low- and middle-resource settings. During the first few months of the pandemic, we observed this model of local production shifting to high-income countries (HICs). Though local production started at a small scale in hospitals and pharmacies, production at an industrial level soon became essential to assure sufficient quality and quantity of ABHR. Accordingly, certain perfume, cosmetics, and alcohol manufacturers shifted production to make hand rub at a reasonable price, mainly for health care settings.¹⁻⁴ The ABHR formulation, manufacturing process, quality control, and challenges to local production are four themes that will be explored in more detail later in the chapter.

Local production of masks also increased globally in response to the initial widespread shortage of PPE, and the realization that most of the world was principally dependent on China for its masks. However, this took time to implement, and even though the initial crisis and mask shortage is over, many low resource countries still do not have the infrastructure to make local production of masks a viable option.⁶ Therefore, during the shortage, the decontamination and reuse of health care workers' N95/FFP2 face masks seemed a promising solution and was increasingly studied by institutions all over the world. A significant number of studies in the last six months have focused on this issue, and this chapter will review how such a program would have to be implemented, what factors must be taken into account if attempting to reprocess masks locally, and what methods seem to work best.⁷ It is important to state that decontaminating respirators should only be done in emergency situations where better options are not available.

This chapter will explore both of these phenomena. First, because access to sufficient and high-quality supplies still is an important challenge faced in this pandemic, and secondly because they can teach us lessons for future emergencies. In the age of globalization, global pandemics will undoubtedly become a more regular occurrence. A growing and highly mobile human population encroaching on ecosystems that they have never been in contact with, and changes in land use, are known to influence the frequency of outbreak events of emerging or reemerging pathogens as well as the speed of their spread and distance they cover.^{8,9}

For governments and politicians, preparing for pandemics is a double-edged sword. On the one hand, if a pandemic does not occur, preparing a country for one is seen as a waste of public money; if it does arrive, then whatever preparation was put in place will be seen as inadequate. Global supply chains involve huge infrastructures and multiple high-level stakeholders that are often entrenched in legal and political structures. It is therefore important for national and global health systems and supply chain systems to try to be exactly what they are traditionally not: agile and adaptable to whatever global emergency may present itself. To work toward this technically unachievable goal, studying what measures can be implemented constructively in the face of supply chain failure is valuable.^{6–9}

Both local production and reprocessing of N95 masks have been implemented in numerous areas around the world. By analyzing how the implementation of these measures worked and the challenges that were faced, we can analyze what measures worked in which geographic regions, how they were implemented, and the aspects that determined their relative success or failure. Studying this means that not only will countries or regions be better prepared if faced with the same challenges, but also that they can undoubtedly apply some of the broader aspects of their experiences to address novel future challenges that affect the global supply chain.^{7–9}

15.2 Evidence in the literature of hand hygiene and masking for preventing transmission of SARS-CoV-2

The main source of transmission of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) is droplets of symptomatic or paucisymptomatic people directly or indirectly by hands and environmental surfaces.^{10–12} That is why both wearing masks and performing hand hygiene are crucial for controlling the pandemic. To limit the virus propagation, public health institutions recommend basic prevention precautions including social distancing, wearing a mask when people are in close contact, hand hygiene, and environmental cleaning.^{13–15}

Masks are a key tool to slowing the pandemic both in the community and in health care settings.^{16,17} There is now sufficient evidence in the literature (including a systematic review published in the *Lancet*) that masks work well for stopping COVID-19.^{18,19} When someone coughs or sneezes, they emit the virus particles inside droplets of mucus of different sizes. Using masks directly decreases the virus droplet numbers that can reach

people and will prevent the droplets produced by coughing or sneezing from entering the nose and mouth of another person, or from contaminating a nearby surface. At the very least, a mask will greatly reduce the number of viruses that are able to reach a nearby person. This will not only help keep people from being infected but will also increase the probability that they only get mild symptoms, since the severity of COVID-19 infection is also dependent on the viral load a person is exposed to.²⁰

A randomized case-control study during the 2009 influenza pandemic determined the value of hand hygiene for the prevention of influenza or influenza-like illnesses that are also transmitted by droplets.²¹ It concluded that “the face mask with hand hygiene group showed a significant reduction in respiratory illness compared to the group with the mask only.”²¹ Hand hygiene is a crucial measure to prevent the cross-transmission as SARS-CoV viruses can survive on surfaces for prolonged periods.²²

Hand hygiene may be performed by two different methods: hand-washing with soap and water or hand rubbing with an ABHR. The latter is preferred in most clinical situations due to its greater microbiological efficacy, better skin tolerance, more practical application, and possible availability in almost all situations especially with the possibility of a pocket-sized dispenser.^{23,24} Enveloped viruses, including SARS-CoV-2, have the lowest level of resistance to ABHR compared to other microorganisms.²⁵ This means that they are generally the easiest type of virus to kill on surfaces and hands, and die very quickly while in contact with alcohol.^{26–29} The evidence of the efficacy of various disinfectants against SARS-CoV-2 is not easy to prove mainly because it is a new virus and microbiological efficacy of in-vitro research methods are more difficult to test on viruses compared to bacteria.^{28,30}

ABHR remains indispensable for preventing the spread of infections.³¹ It is well known that ABHR can be successfully used as an effective infection prevention measure during viral outbreaks. Zika, Ebola, SARS-CoV-1, Middle East respiratory syndrome coronavirus (MERS), and other enveloped viruses are all efficiently killed by the two WHO ABHR formulations.²⁶ A recent study shows that both the commercial and WHO formulations of ABHR can effectively inactivate SARS-CoV-2,³² and that ethanol and 2-propanol at a concentration of >30% inactivated the virus in 30 s. This provides strong evidence supporting the use of ABHR in the context of the COVID-19 pandemic, and it is recommended by the WHO, Centers for Disease Prevention and Control (CDC), and European Center for Disease Prevention and Control.^{13,33–35}

15.3 The global situation since the beginning of the pandemic

The COVID-19 pandemic resulted in significant overconsumption of PPE, including masks, ABHR, and certain medical devices. The demand for some protective equipment has increased by several thousand percent. In the United States, ABHR sales soared 470% in the first week of March 2020, compared to the same period in 2019. Likewise, in Italy, sales of ABHR in supermarkets increased by 561% in the first three weeks of the pandemic compared to the year before.³⁶ Around the world, many supermarkets, pharmacies, hospitals, and other health care facilities all ran out of their stock of ABHR. In Italy, these shortages have been reported to have contributed to the high burden of infections and deaths among hospital staff.³⁷ It is logical to imagine that this also happened in other areas where health care facilities did not have appropriate supplies.

A lack of foresight coupled with the dramatic increase in need have led to the organizational or even the collapse of supply chains. Lockdowns further exacerbated the problem, causing production shutdowns and disruptions to transportation and logistics.³⁸ This is especially pertinent because the countries most affected by COVID-19 at the start of the pandemic are among the countries most involved in global trade. The G7 countries, which include China, Japan, the United States, France, Italy, United Kingdom, and Germany are responsible for 65% of world manufacturing and 41% of world manufacturing exports.³⁸

At the beginning of the pandemic, being able to procure supplies was only the first major challenge; the next one was being able to pay for them. In the absence of a national or international price control program, the prices of PPE skyrocketed.³⁹ According to the WHO, the prices of surgical masks increased sixfold, tripled for N95 respirators, and doubled for gowns.⁴⁰ Market manipulation was a global phenomenon, with stocks of supplies often being sold to the highest bidder, and stories of governments buying supplies off the tarmac destined for other countries.⁴¹ This competition disproportionately benefited economically powerful countries and could potentially leave those with smaller budgets in need of equipment, thus further widening inequalities. This has resulted in approaches such as accepting donations of homemade PPE and reusing materials. It goes without saying that these strategies are far from ideal; if the quality of PPE is inadequate, or a protocol for reuse is not well implemented, it jeopardizes the safety of the people that rely on it to protect them.⁴²

15.4 Strategies to adapt

Never since the beginning of the globalized world economy have so many countries needed the same resources at the same time. For both masks and ABHR, various countries have been loosening restrictions on manufacturing to encourage local production and meet the demand for these.²

For ABHR, the options for addressing shortages are limited to ameliorating supply chain/distribution networks and increasing local production. The formula can be made principally from either ethanol or isopropyl alcohols, but there is not really a way around their availability, as the composition is quite limited by the specific molecules needed. During a pandemic, it is crucial for local governments to reinforce the already existing ABHR production and distribution networks. If these measures are not adequate to cover the increasing demand, it is essential for them to create new networks by working with companies that are already well equipped for production of similar products at large scale. Small-scale production in pharmacies or health care facilities (HCF)s can also be implemented. For masks, the fabric used is not as limited, in the sense that different materials can function as a mask, and therefore a number of materials can be tested and considered.⁴

Local regulations have to be adapted to the extraordinary situation in order to facilitate local production. Japan is a good example: in order to facilitate access to priority equipment, the government established cooperation between private companies for PPE such as surgical masks, ABHR, and medical devices including ventilators. It has put in place facilitative measures such as subsidies for investments in the factories producing the masks and PPE, support for the purchase of raw materials and the deregulation of alcohol consumption. The Japanese government was thus able to provide their hospitals with the necessary PPE, including 45 million surgical masks.³

In Switzerland, the solidarity of many companies and individuals brought about the implementation of a national plan for local ABHR production increased the availability of ABHR and avoided major shortages, as well as excessive pricing.⁴³ In certain countries including France and United States, they passed specific laws during the crisis to cap the price of masks and ABHR in order to maintain a reasonable cost of these essential products.^{44,45}

In response to the challenge of inequality faced to this global shortage, the WHO and several partners have set up a procurement portal through

which countries can order PPE.⁴⁶ Although members of this procurement portal can advise on prioritization between countries, there is no formal international mechanism for allocating PPE to regions that are most in need. Ideally countries would prepare plans for how to handle shortage, otherwise situations where some countries have no access to supplies and others have a surplus, are more likely.⁴⁷

15.5 ABHR local production

15.5.1 WHO and the global implementation of ABHR

Studies have shown that as many as 50%–70% of infections are transmitted through hands due to a lack of proper hand hygiene during daily patient care.⁴⁸ Proper hand hygiene can be achieved by using a product that has proven antimicrobial efficacy and when users performed it at the right time and in the right way. According to the WHO multimodal strategy for hand hygiene improvement,⁴⁹ five elements are considered essential for achieving best practices. The first of these is “system change,” i.e., the implementation of a system making ABHR available wherever it is needed in sufficient quantity and quality.^{24,49} Over the past decades, this strategy has been largely implemented all around the world in order to enhance patient safety in HCF.^{23,50}

Commercially available ABHR is produced mainly in HICs, and “system change” has been fully implemented in all HCF in these countries. However, in low- and middle-income countries (LMICs), these products are seldom commercially available and their cost can exceed the cost of ABHR in HICs mainly due to transportation and importation fees, making it completely unaffordable.⁵¹

To overcome this problem and to facilitate the development of a global approach to hand hygiene improvement in health care, the WHO developed two alcohol-based formulations for hand rubbing, which were tested and validated for antimicrobial efficacy and skin tolerability.^{23,52,53} These were made patent-free to facilitate production and affordability to all institutions globally. These ABHR formulations are so vital to health care that they are classified as Essential Medicines by the WHO.⁵⁴ Access to ABHR is therefore also a central component of the WHO’s overall objective of universal health coverage.^{55,56}

WHO formulations of ABHR are recommended by the WHO Guidelines on Hand Hygiene in Health Care settings,²³ and the specific methodology adapted for their local production were tested in pilot sites

mostly located in LMICs. Alcohol for hand rub can be manufactured from a distillation process using the byproducts of crops such as manioc, bananas, corn, and sugarcane, many of which are cultivated in the majority of LMICs.⁵ The WHO formulation for ABHR, little known to HICs before 2020, has now become very popular. The views of the e-learning video developed by the University Hospitals of Geneva pharmacy, which details the process of the production of the WHO formulation production increased from 5000 to 52,000 since the start of the epidemic (as of September 9, 2020).⁵⁷

15.5.2 ABHR formulation

The formulation of ABHR product is important for the microbial efficacy, tolerance, and acceptability of users.^{23,58} For safety and practical reasons, it is better to keep it simple and to use well-known active ingredients and excipients. The WHO formulation is made up of alcohol (active ingredient), glycerol (emollient), peroxide hydrogen (sporicide), and water. All these ingredients are ubiquitous, inexpensive, and have been well-known for many years.^{5,23}

The active ingredient is the alcohol. The efficacy of alcohol is affected by type of alcohol, its concentration, contact time, and skin conditions.²³ Ethanol, isopropanol, n-propanol, or a combination of both are commonly used as active agents.⁵⁹ They are active against bacteria, all enveloped and most nonenveloped viruses.⁶⁰ Contrary to other antiseptics, alcohol used in this way does not have the potential to develop bacterial resistance.^{27,61} Though there is limited evidence for bacterial tolerance of certain strains after long-term exposure to low concentrations of alcohol, there is no evidence of any resistance to any alcohol at concentrations of anywhere near 60%, which is the minimum required concentration for ABHR.^{62–64} The reason is that alcohol's mechanism of action is specific. Alcohols are rapidly germicidal on hands through protein denaturation.^{25,60,65} The effective and safe concentration of alcohol for disinfection is between 60% and 95% (v/v) according to the CDC and the WHO,^{14,59,66} including for use against SARS-CoV-2. The WHO recommended to use a concentration of ethanol at 80% (v/v) (formulation 1) or a concentration of isopropanol at 75% (v/v) (formulation 2). Recent studies showed that increasing concentration of alcohol in ABHR by 5% (v/v) could reduce the contact time necessary to be effective.⁶⁷

Adding an emollient to the formulation is crucial to improve skin tolerability, but it can also reduce the effectiveness of the alcohol, thus an adequate balance should be found between the two to ensure both efficacy and acceptability.⁶⁸ Alcohols are not effective against spores, making a sporicidal agent necessary to avoid the presence of viable bacterial spores in the final product.⁶⁹ The solution could be a filtered method (0.22 μm) during the filling bottle process, or a sporicidal such as hydrogen peroxide could be added at low concentration, which is active against spores after 72 h.⁷⁰ Other potential additives besides the emollients and the aforementioned sporicidal agents include viscosity enhancers, buffers, preservatives, colorants, and fragrances, though not all products have all of these.^{5,59} Many nonessential additives can influence the antimicrobial activity, which is why the efficacy of the final product must be carefully evaluated for every formulation. Though nonessential additives are often used to enhance the acceptability of the product, they can decrease the tolerability and increase the risk of allergenic properties.^{59,68–70}

15.5.3 Manufacturing process of ABHR

Industrial manufacturing is the best way to provide ABHR in quality and quantity. On the one hand, for safety reasons, it is essential to have premises suitable for the preparation of alcohol and storage of the finished product. One needs a spacious facility that is ventilated and not accessible to outsiders. The automated production chain of large-scale industrial production means more quick and efficient filling of bottles and printing and application of labels with less staff necessary. Still, certain situations make local, small-scale production necessary in pharmacies, hospitals, or others strategic places which has been the case in sanitary crisis situations.⁷¹ This type of emergency manufacturing can adversely affect the quality of the final product.³⁶ The selected components and the manufacturing process are the variables that ultimately influence the quality of the final product, so production and quality control are crucial.

All parameters of such production including the facility, the operators, the documentation, the production process and quality control must be in accordance with good manufacturing practices (GMP).⁷² The GMP are the minimum standards that a product manufacturer must meet in their production processes. The GMP limits the risks of cross-contamination of products (by an internal or external contaminant) and the risks of confusion, in particular with regard to labeling and the identification of ingredients.

These standards insist that hygiene and organizational practices must be implemented at all levels. The level of GMP depends on local regulations and volume of hand rub produced.⁷³

Because the expected efficacy of the preparation will be developed only if their quality and quantity corresponds to the procedure, it is important to maintain a high standard of quality control of both the raw materials, especially active ingredients, and of the final product.⁷³ Regarding the concentration and dosage of alcohol, gas chromatography is the gold standard for production, but simpler procedures such as alcoholmeters can be used as recommended by the WHO.⁵ According to the WHO guidelines of local ABHR production, simplified methods could be implemented to production and quality control processes in difficult contexts such as a pandemic. Other active ingredients such as hydrogen peroxide should also be analyzed in the final preparation.^{5,57} In theory, even “inactive” components, such as emollients or perfumes, should be controlled since the effectiveness of ABHR is also dependent on these components.^{5,57}

An e-learning about the production process at a local level is available freely online to increase access.⁵⁷ No guide or training for the ABHR manufacturing process exists at this time.

15.5.4 ABHR production challenges

Although analysis of the feasibility testing, quality control, and costs of local ABHR production have led to very encouraging results, particularly in terms of cost reduction compared to commercial products in LMICs, there are still challenges.^{5,51} Some of these have always existed and are inherent to the process of local production, especially in LMICs, where there are both common and widespread. One of the main challenges lies in the procurement of the main ingredients and containers as all the necessary raw materials are not produced locally in most cases. There are also a number of constraints link to distribution, due to the flammability of alcohols. The flash points of ethanol 80% (v/v) and of isopropanol 75% (v/v) are 17.5 and 19°C, respectively, meaning that adapted transportation methods are necessary to move alcohols or ABHR between locations.⁵ Furthermore, disruptions of regular budget allocations for buying ABHR are frequent in LMICs. Governments, institutions, HCWs, or patients themselves could be the buyer. This question remains unresolved in low resources settings, disrupting the procurement of ABHR needed for the continuity of quality care.^{51,74}

With the arrival of the pandemic, these issues, once confined to LMICs, became a global problem. Although low resources settings faced the brunt of challenges and shortages, COVID-19 exacerbated the existing issues with local ABHR production for everyone. Even HICs were faced with difficulty in supplying alcohol and appropriate containers that were both easily transportable and compatible with alcohol. Help often came from the private sector; cosmetics, perfume, and beverage packaging helped in production, packaging, and distribution of ABHR. The solidarity and creativity shown by industries during this time helped to successfully compensate for this lack of ABHR, and ensure that remains available at reasonable prices.^{43,75}

Regulation of alcohol sales and distribution is also often problematic since these laws are often not adapted to this extraordinary situation. In certain European countries, such as in Switzerland, WHO formulations do not meet the standards for biocidal products for use in HCFs.⁷⁶ This is due to the fact that commercially products are usually used in these countries. Due to the high standards of European norms, the WHO formulation in its current incarnation does not pass the European norms, and thus cannot be sold commercially to health care facilities within Europe (publication EN and WHO formulation). The same challenge regarding the WHO formulation is also present in other HICs. However, translating the WHO formulations from v/v to w/w and reducing its glycerol content to 0.5% resolves this issue. Because alcohol consumption is harmful to human health, some countries including Japan or the United States implemented local regulations to limit the importation, distribution, and sale of the substance over the country without distinguishing between drinkable alcohol and pharmaceuticals.^{3,77} If this regulatory aspect is not revised during a pandemic, regulations can block the production and prevent the use of the final product.

15.6 Masks/filtering face piece respirators

It is important to note that we will mostly be covering surgical and N95 face masks in this chapter. Cloth face masks were often recommended for use in the community as a stopgap during the time period where there was a drastic lack of supply until surgical mask importation or production could increase to the point where there were enough for use in both health care facilities and in the community.⁴

Surgical masks and even some cloth masks are able to stop most of the droplets in which the viruses reside, but N95 masks are the only ones that can actually physically stop the SARS-CoV-2 virion. Mask filters collect particles through a variety of mechanisms: inertial impaction, diffusion, interception (which some authors argue is a form of diffusion), and electrostatic attraction (Fig. 15.1).^{78–80} Disposable surgical masks are recommended for the general population because they are less expensive, and easier and more comfortable to wear. Because COVID-19 is mostly transmitted by hands or droplets, surgical masks are sufficient for protection in the community, and in most clinical activities in health care settings. N95 masks are recommended for situations when health care workers are taking care of patients known to be infected with COVID, especially if they are performing procedures such as tracheal aspirations that could cause the aerosolization of the virus. N95 masks are designed to create a seal around the face, and people need training to wear them correctly. Furthermore, because they are uncomfortable, a person who has not been trained on their use or in hand hygiene will be more likely to touch or adjust the mask without thinking, potentially contaminating it and rendering it useless.^{4,78–80}

Before exploring the possibility of reusing masks, it is important to state that no matter the method of decontamination, this process is not recommended if other options are available. Not only do the decontamination methods have very little evidence for clinical efficacy and safety outside of a laboratory setting, but as the process is relatively complex, there are many opportunities for mistakes to be made.^{78–80}

15.7 Logistics

Although much attention has recently been given in the literature to the different methods of mask decontamination, there is little in the way of recommendations concerning the collection and redistribution systems for those masks. If the masks cannot be collected, stored, reprocessed, and returned in a safe and orderly way, even a potentially excellent decontamination method will fail. It is important to note that each method of decontamination is quite labor intensive and involves numerous people besides the health care workers that need to wear the mask.^{40,78–81}

Because masks cannot be washed or disinfected before being reprocessed, the safety of the process cannot be guaranteed. Therefore, it is important that the collection and distribution of the masks is individualized,

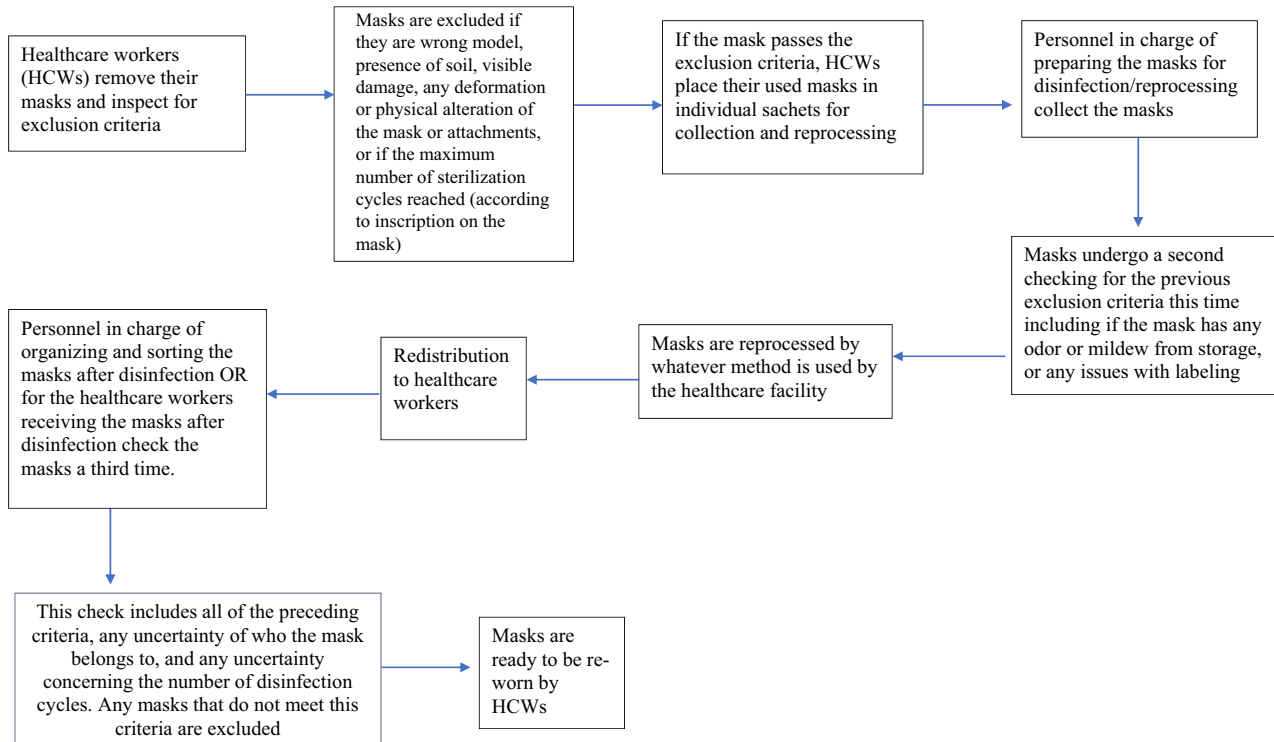


Figure 15.1 Flow chart for the logistics of mask reprocessing.

meaning that a specific mask must go back to the person that wore it the first time. Even if the decontamination process is 100% effective on SARS-CoV-2, this is a very easy virus to destroy, and other more tenacious microorganisms such as spores or mycobacteria might not be as easy to kill. This is especially an issue if the masks are soiled, and though they would be inspected for any soil before reprocessing, a visual inspection will inevitably miss some residues.^{80–83}

Nonetheless, this visual inspection is the starting point of any mask reprocessing, and only eligible masks should undergo decontamination. Any visible soil or wetness (including mucus or lipstick stains), damage to the mask's integrity, or problem with the elastic bands mean that the mask should automatically be discarded.^{7,40,81} It is also important that each mask is reused by the same health care worker, if one does not know who a mask belongs to, it should be discarded as well.^{40,82} This will prevent and transmission of microorganisms between the health care workers if the decontamination procedure fails, or in the case that the method not effective enough to kill the microorganisms that are more tenacious than SARS-CoV-2 (Fig. 15.2).⁸³

15.7.1 Decontamination and reuse

The minimum requirement for a method of decontamination is disinfection, meaning a minimum of a 3-log reduction in the pathogen tested.⁸⁴ If a method reaches sterilization, this means that a 6-log reduction of the microorganism has been reached. It is crucial that the masks are not damaged by the decontamination process. If the physical integrity, filtration capacity, or the electrostatic charge of the masks (which greatly increases the mechanical filtration capacity) is damaged, the mask is rendered useless.⁸⁵

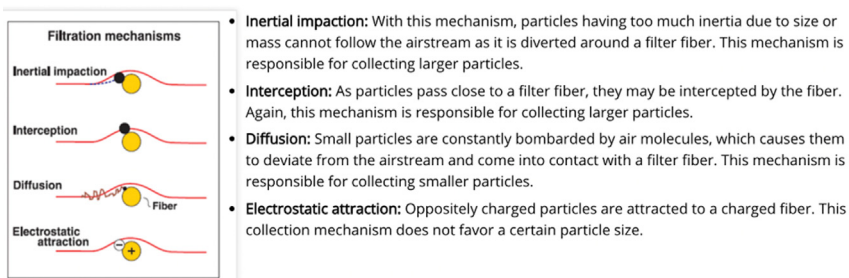


Figure 15.2 How masks work. (Source: *N95 respirators and surgical masks* | Blogs | CDC. Available from: <https://blogs.cdc.gov/niosh-science-blog/2009/10/14/n95/>.<https://blogs.cdc.gov/niosh-science-blog/2009/10/14/n95/>).

In order to be recommended for an emergency situation such as a shortage of masks, decontamination methods need to be both microbiologically effective (with a minimum of 3-log reduction in microbial contamination), and be able to be performed without any physical damage to the masks themselves. Not all methods that have been tested were able to reach these standards. Notably, liquids such as ethanol, sodium hypochlorite, detergent wipes, and benzalkonium chloride wipes, as well as UVA rays performed insufficiently.^{86–89} There are some methods of decontamination that are able to effectuate disinfection and sterilization. It is important to note that the success of an experiment may vary depending on what model of mask they are testing on. When reviewing the literature, we found quite a high degree of variation, even within the same study if the models of the masks tested were different. Gasses such as ethylene oxide, gaseous hydrogen peroxide (with or without peracetic acid), peracetic acid dry-fogging system, and ozone all performed quite well,⁹⁰ although ozone tended to deform the rubber band that attaches the face mask, which potentially disqualifies that method for some masks.^{91–93} Heat-based disinfection includes dry heat, moist heat, microwave-generated moist heat, and steam (under pressure). In terms of physical degradation of the masks, all of these methods performed well in terms of fit and filtration. Microbiologically, these methods varied in efficacy, with dry heat being the least effective.⁹⁰ Still, because these methods are among the simplest to implement, they will no doubt be important for use in low resource environments. Ultraviolet germicidal irradiation (UVGI) using UVC rays could also be quite effective in some experiments, but the results seemed to be less consistent.⁹⁰

It is important to note that most of these experiments were not performed on SARS-CoV-2, which is probably good, since the virus is relatively easy to kill. One could argue that a number of the methods that performed well on microorganisms that are far more difficult to kill than SARS-CoV-2 inherently allows for a margin of error. This is meant in the sense that even if the method performed significantly less well in clinical settings than in laboratory settings, there is still a high chance of it being effective against SARS-CoV-2.^{84–90}

When analyzing which method of decontamination to implement, it is important for institutions to review a number of factors. Each of the methods have different requirements in terms of the microbiological efficacy of the method, the time needed to complete the decontamination, the cost, risks for staff, the complexity of the procedure, the infrastructure or

equipment needed, and whether the decontamination method can be used repeatedly on the same mask without degrading the material. Some of these methods require very specialized machinery or can be toxic if not deployed properly or if the masks are not allowed to off-gas. Other methods are incredibly simple, with some experiments even seeing how masks could be decontaminated effectively with widely available equipment such as microwaves and electric rice cookers. Ultimately, if an institution is forced to resort to decontaminating N95 masks, the method that they should use is the one that they can implement correctly and use safely.

15.7.2 Local production

Before resorting to decontamination, many countries have been working on increasing their own capacity to produce masks. Although the local production of face masks is now widespread, it is a very new phenomenon, and thus has not been extensively discussed in the literature. One important difficulty in the process is the nonwoven materials from which the mask is manufactured; the most popular material is melt-blown polypropylene. This material, which consists of very thin plastic nanofibers, is made by complex machines that cost almost €4 million.⁸⁷ The quality of the masks depends, in part, on the precision of these machines. One crucial part of local production is to find cheaper viable alternatives to these machines.^{84–90}

Electrospinning is another production method that can produce the nanofibers needed for face masks, and it is generally a more simple process, though productivity is generally higher with melt blowing.⁸⁸ Polymers with higher molecular weights are more likely to make thicker fibers with electrospinning than with melt blowing. Generally, either additives or injected fluids are needed for both production methods.⁸⁸ One study looked at simplifying this process to increase the local production of polypropylene masks by modifying cotton candy machines to produce nanofilaments of polypropylene. It also explored the possibility of using a car battery as a source of electricity.⁷⁸

Locally produced N95 masks are currently being produced, used, and tested. One study, which looked at a number of different criteria including breathing resistance, virus filtration efficacy, NaCl particle penetration, and fit, analyzed locally produced masks made of various layers different types of nonwoven polypropylene fabric. They found that the locally produced masks were able to achieve similar filtering capacities as FFP2/N95 masks, which is encouraging for local production.⁹³

15.7.3 Other methods and materials

Another strategy that is not discussed here in detail is the extended use of surgical/N95 face masks instead of disposing them as often as recommended.^{7,94} This strategy is more difficult to assess, because of how it was implemented often varied from one institution to another, and was directly dependent on what masks were available at any given time. Generally, this strategy includes guidelines of when a mask is to soiled to reuse, wearing a cleanable face shield over the mask to protect it from contamination, and how to fold and store masks for reuse as safely as possible.⁹⁴

In some instances, strategies have also been implemented to change the manufacturing materials used in production or for repurposing other PPE for making masks. One study looked at repurposing surgical wrapping for creating masks that performed close to the filtration capacity of N95 masks, and with a single layer of the material, worked well to replace surgical masks.⁹⁵ Some others looked at using commonly available materials such as polyester, silk, nylon, etc., what their filtration and breathability is, and in one case, whether these materials could be triboelectrically charged to increase filtration.^{96,97} Another study looked at the effect of combining different fabrics such as silk, chiffon, and cotton to create hybrid masks. They seemed to have a higher filtration than masks made with a single type of fabric, possibly in part due to the combined effect of both mechanical and electrostatic filtration.⁹⁸

15.7.4 Looking forward

To optimize local production in the future, it is important to work with supranational organizations, governments, and nongovernmental actors. Often, public–private partnerships work well for such endeavors and help to ensure their sustainability. Concerning the reuse of masks, it is far better to focus on a steady supply and reducing the need for them to be reused, and the safety and these procedures are difficult to ensure, and the financial cost of implementations can be higher than buying new disposable masks.^{94–98}

15.8 Conclusion

The current COVID-19 pandemic has challenged the world in unprecedented ways, and forced countries and international organizations to rethink the globalized economy as we know it. Implementing aspects of

deglobalization and ensuring sufficient local production and access to the most crucial products for community health has become a high priority for everyone. Access to masks and ABHR are crucial for health care facilities and for the community. The success of infection prevention programs depends on them. The pandemic has shifted how the world thinks about its resources and production, and countries around the world have tackled the issues of locally producing masks and ABHR, producing masks with different materials and equipment and decontaminating and reusing them if there are no other viable options.

In this unprecedented global crisis, local production is crucial. It has a number of potential advantages over products imported from other countries. It is more affordable and therefore more accessible at the point of care/need. It could help the development of the local economy and create local jobs, which in turn could ensure sustainability of ABHR availability. Such production could positively influence health policies and increase community awareness about the importance of IPC measures. Lastly, it could make current IPC measures and programs more sustainable, and prevent cross-transmission in the long term, preparing the health system for a potential future pandemics.

Humans are resourceful creatures in times of adversity, but some of the measures taken during this time should be lasting. Being more self-sufficient in infection prevention during a pandemic is an issue of both national and international security. It will be in countries' best interest to continue to explore the avenues of self-sufficiency; not least because this will simultaneously contribute to addressing issues of access to basic health supplies in low resource areas around the world.

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