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Review Article

Face Mask as a Tool to Prevent the Coronavirus Disease 2019: The Importance and Challenges

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Abstract

Context: Coronavirus disease 2019 (COVID-19) emerged in China in December 2019 and rapidly became a global epidemic. Respiratory droplets are the main transmission route, and no approved drugs or vaccines have been reported so far. Therefore, prevention is considered essential to the control of this pandemic. Masks are personal protective equipment, which play a key role in the prevention process. The World Health Organization (WHO), Centers for Disease Control and Prevention (CDC), and European Center for Disease Prevention and Control (ECDC) have emphasized on the use of masks by healthcare providers, patients, and caregivers.
Evidence Acquisition: This review study was conducted by searching in Scopus, PubMed, Google Scholar, and WHO library databases using specific search terms. Only the articles and other secondary sources published in English were selected and reviewed.
Results: 2019 novel coronavirus (2019-nCoV) is smaller than the pore size of all types of available masks. In addition, the issue of limited hospital resources (e.g., masks during pandemics) requires special attention, while the produced mask garbage during the pandemic is another crucial issue. Efforts have been made to address these three critical challenges.
Conclusions: We reviewed various types of masks and investigated the ability of each to prevent COVID-19, as well as the solutions for the issues associated with using the masks that provide insufficient protection against the 2019-nCoV, mask shortage, and mask garbage. Despite the deficient protective power of the available masks, these tools could delay the progression of COVID-19 effectively owing to mask flow resistance and virus spread via droplets.

Keywords: Antiviral Mask, Coronavirus Disease 2019, Masks, Pandemics, Prevention

1. Context

Coronaviruses are a group of enveloped viruses that have a single-stranded, positive-sense RNA genome. These viruses have the diameter of 60 - 140 nanometers and are known as coronaviruses because of the crown-like spikes protruding from their surface. Six known coronaviruses could infect humans and cause respiratory diseases. Severe acute respiratory syndrome (SARS) and Middle East respiratory syndrome (MERS) coronaviruses are zoonotic and highly pathogenic viruses, which have led to global and regional pandemics (1-3).

The 2019 novel coronavirus (2019-nCoV) or SARS-CoV-2 was first detected in December 2019 in Wuhan, China and rapidly spread to other parts of the world. SARS-CoV-2 has more than 70% similarity in terms of the genetic sequence to SARS-CoV. The main transmission route is through the respiratory droplets of the symptomatic or asymptomatic positive patients or patients who are in the clinical remission phase. These droplets travel about 1-2 meters while eating and talking and about 4 - 8 meters while sneezing and coughing; therefore, social distancing (minimum of two meters according to CDC) must be observed in public places. Infected respiratory droplets could also be found on various surfaces, and the disease could be transmitted via inhaling respiratory droplets or touching contaminated surfaces followed by touching the nose, mouth, and eyes. Furthermore, the nucleic acid of the virus has been detected in feces, while there have been no public reports of fecal-oral transmission (4-10).

To date, no approved drugs or vaccines have been introduced for the coronavirus disease 2019 (COVID-19). On the other hand, the disease has become highly prevalent and labeled a pandemic; therefore, it is essential to take effective preventative measures. Social distancing and hand washing are the best suggestions to prevent the infection. Another suggestion in this regard is to use personal protective equipment (PPE), such as masks, eye protectors, and gloves (1, 11-14).

According to the recommendations of the World Health Organization (WHO) regarding COVID-19, more protective face masks should be prioritized for healthcare providers and caregivers (15). Medical staff should wear a surgical mask during routine care and a respiratory mask while providing care to COVID-19 patients (16, 17). According to the WHO recommendations, if people have to leave the house, they must wear a mask to control the epidemic because the individual or community members may be infected and asymptomatic (15). CDC and ECDC have also emphasized on the use of face masks with filters by medical staff while providing care to the patients. According to the CDC recommendations, it is mandatory to use conventional and even cloth masks (face masks without filters) in public places (e.g., supermarkets), and surgical masks and respirators should also be used by medical staff and patients more frequently (16-18).

Although masks do not allow many droplets to pass through, some small particles may pass through the mask (8). Notably, non-standard methods of using and replacing masks will lead to self-contamination. The WHO has warned that when healthy individuals use face masks, they should not neglect the use of hand sanitizers and maintenance of physical distancing (17, 19-21). The imperfect protective properties of masks have led researchers to seek other solutions and produce improved masks that ensure the better control of COVID-19 and prevention of the further spread of the pandemic (11, 12).

2. Objectives

The present study aimed to investigate the shortage of mask resources and the related solutions, while also reviewing various types of available masks and the technologies used to enhance the protective features of these masks and seeking approaches to solve the mask garbage issue.

3. Evidence Acquisition

The documents used in the current research included journal articles, letters, and other secondary sources. The review was conducted by searching in Scopus, PubMed, Google Scholar, and WHO library databases using keywords such as "(COVID-19) or (coronavirus) or (SARS-CoV-2) or (2019-nCoV)" and "(mask) or (face mask) or (medical mask) or (surgical mask) or (respirator) or (respiratory mask)". Further publications were also obtained from the reference lists of the retrieved articles and letters, and the documents published in English were reviewed.

4. Results

4.1. Shortage of Masks and Solutions

The COVID-19 outbreak has led to the shortage of hospital resources in different countries. One of these resources is PPE, especially the masks that are used by medical personnel and the public (13, 22). Mask shortage could be perilous for the medical staff, while China has accepted the risk and urged the entire population to use masks in all places. The decision led to mask shortage in China in February, with factories producing about 180 million masks per day, while a total of 900 million masks were needed per day (23).

Considering the high demand for masks and limited resources of PPE, several studies have been focused on the sterilization and reuse of masks. In sterilizing, the pathogens that have penetrated the mask filter must be removed, and the filter should not be destroyed or the mask filtering performance should not reduce. Some studies have investigated techniques such as gamma irradiation, electron beam, ultraviolet irradiation, dry heating, steam heating, vaporized hydrogen peroxide, ethylene oxide, ozone gas, microwave irradiation, and the use of 70% ethyl alcohol for the sterilization of respirators against 2019-nCoV. In general, sterilization procedures are associated with problems such as respirator damage, reaction with mask components or the risks of human safety and health. Among these methods, hydrogen peroxide vapor has been widely recommended. As the worst-case scenario, it has been reported that ethyl alcohol (70%) could make the filter inefficient entirely. Even a convenient technique for sterilization allows the reuse of respirators for a limited number of times. On the other hand, disinfection for the reuse of surgical masks has not been characterized (13, 24-26).

The WHO, CDC, and ECDC recommendations for prioritizing the use of more protective face masks by patients and patient caregivers are considered to be an important approach to the control of mask shortage (15-18, 27). A group of researchers have also developed an interesting and advanced idea for the production and reuse of masks. This method is focused on the production of 3D-printed masks. After installing the FaceApp on their smartphone, people could send their HD scan image (OBJ format) to the email of 3D Infinity Co. in Maldegem (Belgium), and the company will produce a special mask for each individual. The head fixation band (Velcro band) and filter of these masks are disposable components and accessed in specific centers. Furthermore, the other parts of these masks could be disinfected and reused. Considering the prevalence of dangerous pandemics such as COVID-19 and the shortage of filtering face piece level 2 (FFP2; moderate level of protection) and FFP3 masks (high level of protection) for healthcare providers, this idea is a potential alternative that is globally and easily accessible and affordable. It is also possible to use FFP2 and FFP3 class filters in these masks (28, 29).

4.2. Types of Masks

4.2.1. Surgical Masks

These masks are known as surgical masks as they are commonly used by physicians to prevent the entry of infected droplets and aerosols into the mouth and nose (12). Surgical masks are used by both medical staff and the general public and could effectively control the spread of aerosols (16).

Surgical masks must pass standard tests such as EN14683 (European standard) or ASTMF2100 (American Society for Testing and Materials [ASTM] standard). For instance, ASTMF2100 examines bacterial filtration efficiency (BFE), differential pressure, sub-micron particulate filtration efficiency (PFE), penetration resistance (using synthetic blood), and flammability resistance. For conventional surgical masks, the filtration efficiency in BFE and sub-micron PFE tests should not be less than 95%. The mean size of aerosols in the BFE test is approximately three micrometers, while the mean size of these particles in the sub-micron PFE test is about 0.1 micrometer. Due to the non-covered space between the surgical masks and the face, these masks do not provide a high degree of protection (22, 30, 31).

Surgical masks are composed of three layers; the outer hydrophobic coating repels liquids (e.g., blood and respiratory droplets), the middle layer filters particles larger than two micrometers, and the third hydrophilic layer absorbs the liquids and moisture inside the mask (25). In an invention (US20100313890A1) in 2010, surgical masks with additional filters were designed to filter the air from the top, bottom, and around the edge of the mask, and the masks provided a better level of protection compared to conventional surgical masks (30).

Simple inexpensive masks that look similar to surgical masks are also used in crowded places. For instance, these masks were used during the SARS outbreak in China, Hong Kong, Vietnam, and Canada, during the avian influenza outbreak in Japan in 2007, and during the 2009 H1N1 outbreak in the United States and Mexico, successfully reducing the prevalence of respiratory viruses, especially in confined spaces (12).

4.2.2. Respirators

Respirators are used instead of surgical masks when a high level of protection is required (30). These masks could be used for eight consecutive hours, and more prolonged use is possible if the mask is not wet or contaminated (16). There are nine types of respirator filters, including N95, N99, N100, R95, R99, R100, P95, P99, and P100. Respirator filters are divided into three categories of N, R, and P based on the degree of protection against oil aerosols. The N, R, and P series are respectively not resistant to oil, partly resistant to oil, and oil proof. The respirator filters that are able to remove at least 95%, 99%, and 99.97% of particles larger than 0.3 micrometer are known as 95, 99, and 100, respectively. N95 masks are the most commonly used respirators. An N95 mask must pass the National Institute for Occupational Safety and Health (NIOSH) tests, which are more difficult and accurate than the measurements used for surgical masks (30-32).

In conventional surgical masks, air leaks from the top, bottom, and around the edge of the masks. Therefore, it is easier to breathe through these masks compared to N95 respirators although they provide a lower protection level. Respirators such as N95 are entirely fixed to the face and do not allow air to enter from around the edge (without passing through the filter) into the mask due to the sealing layer (30, 33, 34). The outer layer of these masks is hydrophobic and prevents the penetration of liquids. The next layer is an activated carbon (charcoal) filter to remove contaminants and chemicals, the third layer is a high-efficiency filter, which removes particles larger than 0.3 micrometer, and the fourth layer is a soft layer ensuring the comfort of the mask. The outer layers on both sides of the mask are made of polypropylene. The humidity of the storage areas should be controlled, and the temperature should be between 15 - 27°C. In addition, these masks should be kept away from direct sunlight, physical and chemical damage, pollution, and dust. Ethanol, isopropyl, radiation, and high heat could damage N95 respirators filters (25).

Since N95 masks cause increased breathing resistance, they reduce the oxygen that enters the lungs through the inhalation process. For this reason, N95 respirators are not recommended to the individuals with pulmonary or cardiac diseases or those in need of oxygen supplementation. To solve this issue, new masks have been made from polypropylene fibers (diameter: ~25 μm), which are treated with dimethyldioctadecylammonium bromide and have a positive electric charge. Moreover, the treated fibers have been used to produce the edge strip of surgical masks and N95 respirators. The positive charge of the treated fibers acts like a magnet and attracts the microorganisms that often have a negative charge. Polypropylene masks made of treated fibers, which have the same sealing strip on the edges, have been improved compared to the existing N95 masks. Measurements have shown that these masks have the lowest leakage rate, almost 100% filtration efficiency, and low breathing resistance. Therefore, they could be used to prevent the transmission of highly contagious infections (e.g., SARS), as well as an appropriate alternative for COVID-19 prevention (35).

4.2.3. Homemade Cloth Masks

Homemade cloth masks are made of ordinary fabric (e.g., yarn, polyester) and could be combined with layers made of kitchen papers or coffee filters. Cloth masks are inexpensive and easy to make. Although they do not provide ultimate protection against tiny droplets, they are useable in public places with social distancing. After each use, the non-fabric part is replaced, and the fabric could be washed or disinfected using disinfectants or UV rays. These masks could delay the epidemic progression of COVID-19 (18, 36-38). Although fabric masks have poorer performance than surgical masks, their use in public places is worthwhile (19). According to the CDC recommendations for COVID-19 prevention, it is advisable to use this type of masks only when surgical masks or N95 are not available (37).

A study investigated the resistance of various masks to the infiltration of the avian influenza virus, and the results revealed that N95 respirators, surgical masks, and cloth masks (consisting of a polyester layer and four layers of kitchen paper with each paper containing three thin layers) had the resistance rate of 99.98%, 97.14%, and 95.15%, respectively. However, the resistance rate is slightly lower for SARS-CoV-2 as this virus has a higher level of persistence on surfaces and penetration power compared to the avian influenza virus. Kitchen papers are effective in protection against the virus since they have multiple layers, a non-woven structure, and virus-absorbing properties. If homemade masks have a small number of kitchen papers layers, they will have limited protective efficiency. In addition, masks made only of fabric may not be able to protect against SARS-CoV-2 (39).

4.2.4. Biodegradable Masks

The non-biodegradability of the constituents of most masks and the subsequent environmental problems (40) have led some researchers to focus on the production of biodegradable multilayer masks to protect against harmful aerosols. The mask produced by these researchers consists of three layers; the outer layer is designed for the pre-filtration stage to remove large aerosol particles, the second (middle) layer is the main layer of filtration through thin fibers (diameter < 1 μm) and electrostatic absorption, and the third layer maintains the shape of the mask. In the mentioned study, all the mask layers were made of biodegradable poly (lactic acid) (PLA) polymer, while the PLA of each layer differed in terms of some physical and chemical properties. As a result, these masks are classified as FFP1 (low protection level) and FFP2 masks (moderate protection level) (41). In addition, another research team proposed the incorporation of wheat gluten biopolymer, which is derived from cereal industries, into the mask construction; these biodegradable masks have sustainable sources (42).

4.2.5. Antiviral Masks

Antiviral masks are an alternative to increasing protection against SARS-CoV-2. As mentioned earlier, the pore size of the available masks is larger than the SARS-CoV-2 diameter. In addition, the virus survives for several hours after attaching to the mask, which increases the risk of COVID-19 infection. Therefore, some studies have been focused on the use of antiviral compounds to increase the protective power of masks against 2019-nCoV (11, 30).

As plants were used to make antimicrobial drugs in the past, we could add an antimicrobial property to mask filters by adding active herbal ingredients. Some plant species, including *Punica granatum*, *Euphorbia granulata*, *Acacia nilotica*, *Andrographis paniculata*, *Sphaeranthus indicus*, and *Strobilanthes cusia* have active antiviral compounds that do not harm the lungs and could be potentially used in the mask structure. Lupeol is the active ingredient in *Strobilanthes cusia*, the inhibitory effect of which on one of the human coronaviruses (HCoV-NL63) has been confirmed. Masks with these antiviral compounds have the potential to create a high level of protection against 2019-nCoV (11).

Copper oxide is also a potent antimicrobial agent, which inactivates the bacteriophages and viruses responsible for bronchitis, polio, herpes, HIV, and influenza. Recently, the technology of adding copper oxide to fabric fibers, latex, and other polymer products has gained popularity. For instance, the addition of copper oxide to N95 respirators substantially causes anti-flu property in the mask without changing without changing its physical filtration properties. On the other hand, the inner layer, which contains copper oxide, does not cause skin allergies or rashes. These masks do not incur significant additional production costs (12).

According to the literature, carrageenan-sulfated polysaccharides exert selective inhibitory effects on several enveloped and non-enveloped viruses and act by preventing the virus from binding to or entering the host cell. Sulfate polysaccharides produced in *Porphyridium* sp. microalgae are also promising antiviral agents against the respiratory viruses belonging to the coronavirus family. These polysaccharides are compatible with the body, while they are also non-toxic and inexpensive, and rapidly degrade in the environment. These biocompatible components could be used as a coating for sanitary products, including masks, for protection against 2019-nCoV infection (43).

Yeung research team from Hong Kong University of Science and Technology (HKUST) has patented an antimicrobial coating for surface disinfection (44). According to the news on the HKUST website, the team has recently developed an antimicrobial polymer coating that has lethal effects on viruses, bacteria, and even spores. This polymer could inactivate up to 99.9% of highly contagious viruses such as measles, mumps, and rubella, and 99.99% of *Feline calicivirus* (FCV), which is hard to destroy. FCV is a gold standard for demonstrating disinfection efficiency as well as remarkably resistant than 2019-nCoV. According to the disinfection standard issued by the National Health Commission of China, this polymer is non-toxic and safe for skin and the environment. These properties make the polymer a proper component for use in hand sanitizers, air filters, water filters, and masks for public protection against the COVID-19 crisis (45).

5. Discussion

COVID-19 has spread rapidly, challenging the global economic, medical, and public health infrastructures. Prevention plays a vital role in slowing down the epidemic process, and masks are among the most important tools in this regard. Even simple masks were reported to effectively decrease the prevalence of respiratory viral diseases in the past (1, 12).

Among the available masks, respirators have been shown to provide the maximum protection, followed by surgical masks. To improve the protective power of these types of masks, they have been altered to some extent. However, using PPE should not mean the abandonment of other essential prevention principles, such as constant hand washing and social distancing (21, 30). Despite the imperfect protective properties of available masks, use of this PPE is highly recommended for two main reasons. First, the flow resistance of masks causes the air to remain near the head while breathing, speaking, coughing, and sneezing. This mechanism, along with physical distancing, leads to the protection of others. Therefore, even a simple mask with sufficient flow resistance could effectively protect others against infection (Figure 1A). Second, although the diameter of SARS-CoV-2 is smaller than the pore size of all types of the available face masks, the virus is spread in varied size droplets. During inhalation in a SARS-CoV-2-contaminated area, large droplets are easily filtered out by most types of face masks, and masks with better filtering properties could also stop small droplets (Figure 1B) (46).

Researchers have made great strides in addressing the issue of the low protection of face masks against 2019-nCoV. Lupeol, which is an herbal antiviral compound, has been reported to inhibit one of the human coronaviruses. In addition, copper oxide, sulfate polysaccharides derived from *Porphyridium* sp. microalgae, and the polymer produced by HKUST researchers are promising antiviral agents to be used in the mask structure as potential solutions to this issue (11, 12, 43, 45).

Mask shortage is considered to be another challenge during pandemics. Despite the disadvantages of sterilization techniques, they have been recommended in some cases. The WHO, CDC, and ECDC recommendations on prioritizing the use of more protective face masks could be a managerial factor in the mask shortage crisis. In addition, the use of 3D printing technology to produce reusable masks with disposable filters and straps is speculated to be an effective solution, especially to eliminate the health risks posed to medical staff (15-18, 23-25).

Currently available masks are often made of synthetic polymers, and the non-biodegradability of these polymers is another issue that has attracted the attention of some researchers (40, 47). The production of a three-layer mask

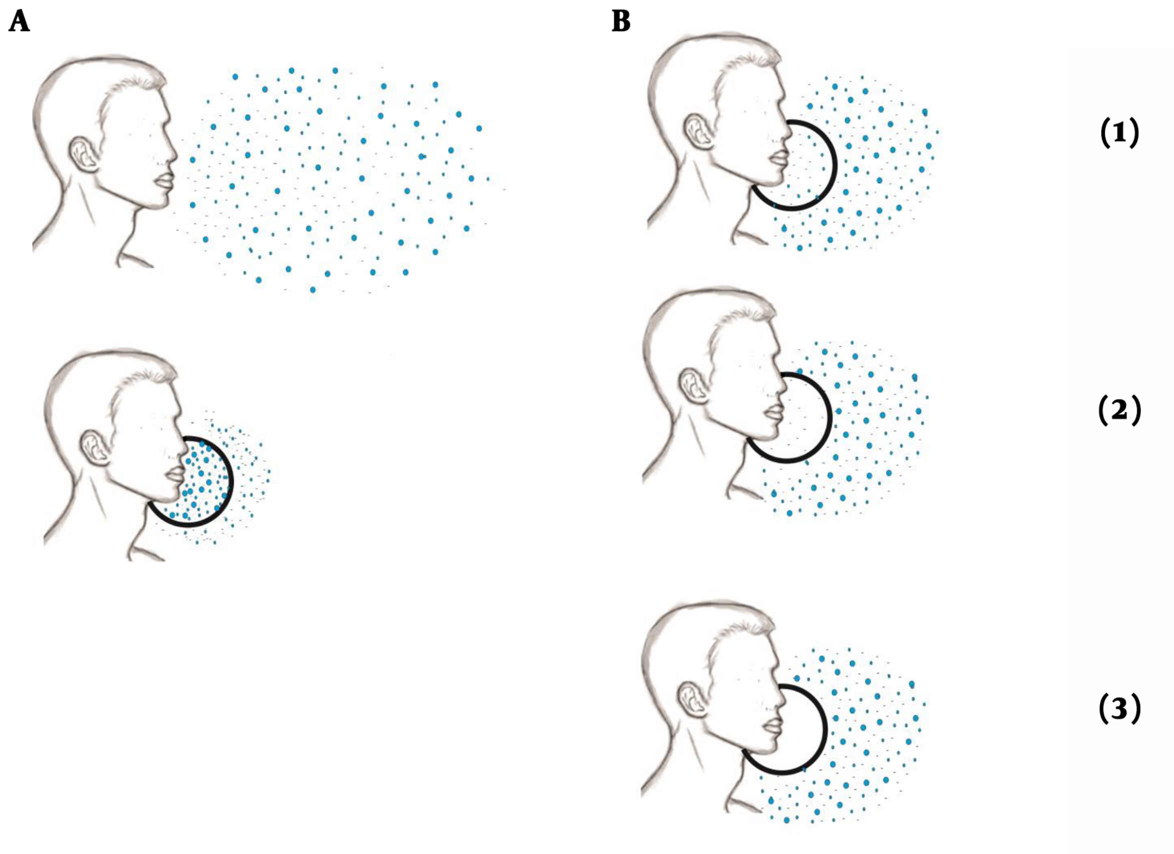

Figure 1. two main mechanisms of protection against 2019-n COV using face masks. A, masks flow resistance limits droplets; B, 2019-nCOV is spread in the form of droplets. From B1 to B3, mask filtering power is increased.

using biodegradable PLA polymer has been an attempt to solve this problem. These masks provide FFP1 and FFP2 protection levels (41). As well as, the use of gluten biopolymer in mask construction is another proposed solution in this regard (42). The addition of natural antiviral compounds, including sulfated polysaccharides and herbal compounds such as lupeol (11, 43), could be a suggestion for improvement the protection level of biodegradable masks against 2019-nCoV, while also maintaining the biocompatibility features of these natural masks. Figure 2 shows a summary of the problems associated with the use of face masks in the COVID-19 pandemic, as well as the recommendations and potential solutions.

5.1. Conclusion

Limited mask resources during pandemics, incomplete protection of this PPE against 2019-nCoV, and mask garbage are three critical problems associated with the use of face masks. Researchers and inventors have been endeavoring to solve these issues, achieving promising results. Although the diameter of 2019-nCoV is smaller than the pore size of the available face masks, use of this PPE is highly recommended as it could delay the progression of COVID-19 infection owing to the flow resistance of the mask and virus spread via droplets.

Footnotes

Authors' Contribution: Farzaneh Barati, Faezeh Habibi Moghadam, and Samin Abbasi Dezfouli prepared and wrote the manuscript. Fakhrisadat Hosseini supervised and guided manuscript finalization.

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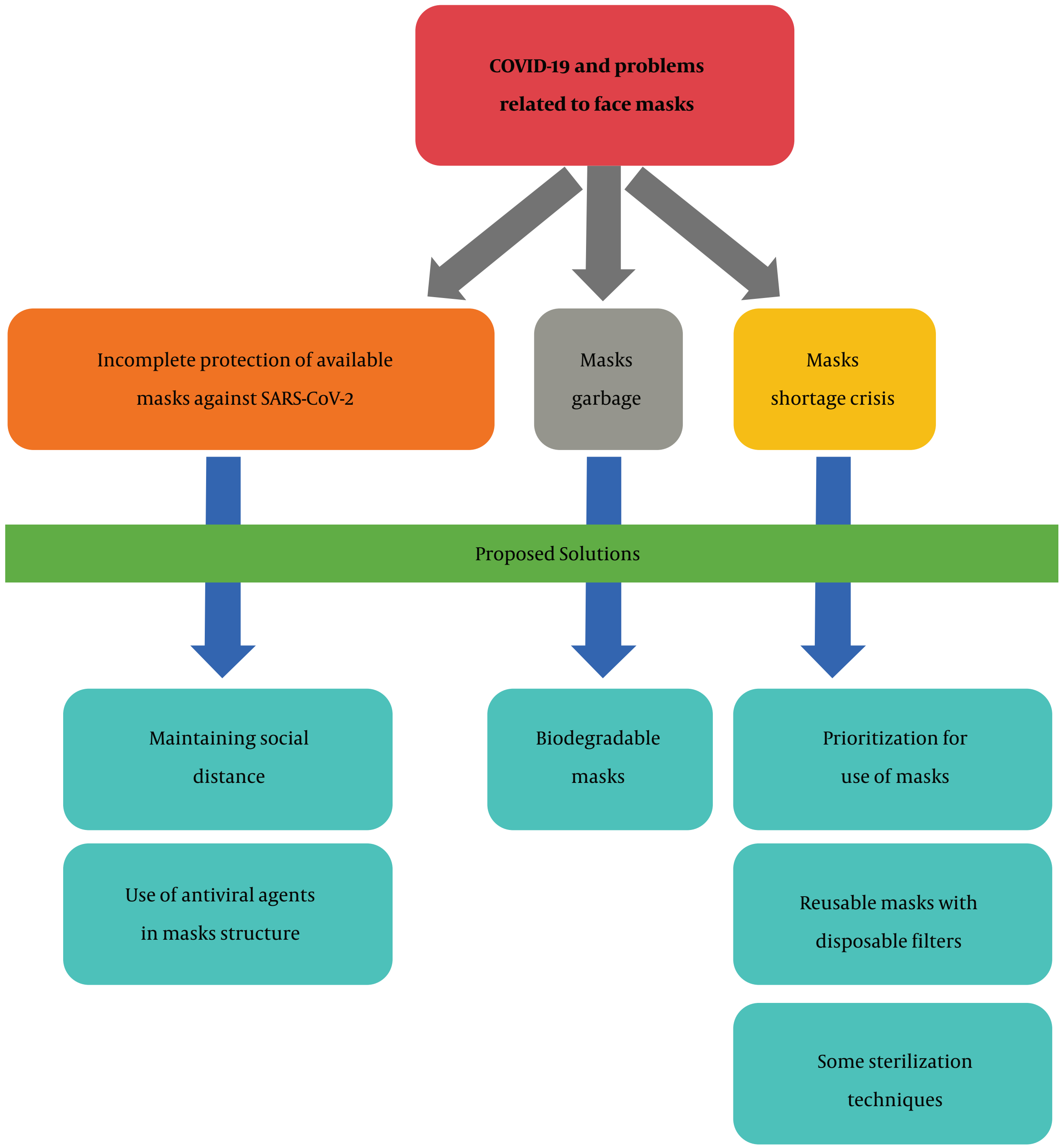

Figure 2. Problems associated with face masks during COVID-19 and proposed solutions

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