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Environmental survival of SARS-CoV-2 – A solid waste perspective

Mahalaxmi Iyer^{a,1}, Sushmita Tiwari^{b,1}, Kaviyarasi Renu^{c,1}, Md Younus Pasha^d, Shradha Pandit^c, Bhupender Singh^e, Neethu Raj^f, Saikrishna Krothapalli^f, Hee Jeong Kwak^g, Venkatesh Balasubramanian^f, Soo Bin Jang^g, Dileep Kumar G.^h, Anand Uttpalⁱ, Arul Narayanasamy^j, Masako Kinoshita^k, Mohana Devi Subramaniam^a, Senthil Kumar Nachimuthu^l, Ayan Roy^e, Abilash Valsala Gopalakrishnan^c, Parthasarathi Ramakrishnan^b, Ssang-Goo Cho^{g,**}, Balachandar Vellingiri^{f,*}

^a Department of Genetics and Molecular Biology, Vision Research Foundation, Chennai, 600-006, India

^b Computational Toxicology Facility, Centre for Innovation and Translational Research, Environmental Monitoring and Intervention Hub (DSIR-CRTDH), CSIR-Indian Institute of Toxicology Research, Vishvgyan Bhawan, 31, M. G. Marg, Lucknow, 226001, Uttar Pradesh, India

^c Department of Biomedical Sciences, School of Biosciences and Technology, Vellore Institute of Technology, Vellore, 632 014, Tamil Nadu, India

^d Department of Medical Laboratory Technology, School of Medical and Allied Health Science, Sanskriti University, Mathura, Uttar Pradesh, 281401, India

^e Department of Biotechnology, Lovely Professional University, Punjab, 144411, India

^f Human Molecular Cytogenetics and Stem Cell Laboratory, Department of Human Genetics and Molecular Biology, Bharathiar University, Coimbatore, 641-046, India

^g Department of Stem Cell and Regenerative Biotechnology, Konkuk University, Seoul, South Korea

^h Department of Seed Science and Technology, Tamil Nadu Agricultural University, Coimbatore, 641003, Tamil Nadu, India

ⁱ Department of Life Sciences and the National Institute for Biotechnology in the Negev, Ben-Gurion University of the Negev, Beer-Sheva, 84105, Israel

^j Disease Proteomics Laboratory, Department of Zoology, Bharathiar University, Coimbatore, 641046, Tamil Nadu, India

^k Department of Neurology, National Hospital Organization Utano National Hospital, 8 Ondoyama-Cho, Narutaki, Ukyo-Ku, Kyoto, 616-8255, Japan

^l Department of Biotechnology, Mizoram University (A Central University), Aizawl, 796 004, Mizoram, India

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ABSTRACT

The advent of COVID-19 has kept the whole world on their toes. Countries are maximizing their efforts to combat the virus and to minimize the infection. Since infectious microorganisms may be transmitted by variety of routes, respiratory and facial protection is required for those that are usually transmitted via droplets/aerosols. Therefore this pandemic has caused a sudden increase in the demand for personal protective equipment (PPE) such as gloves, masks, and many other important items since, the evidence of individual-to-individual transmission (through respiratory droplets/coughing) and secondary infection of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). But the disposal of these personal protective measures remains a huge question mark towards the environmental impact. Huge waste generation demands proper segregation according to waste types, collection, and recycling to minimize the risk of infection spread through aerosols and attempts to implement measures to monitor infections. Hence, this review focuses on the impact of environment due to improper disposal of these personal protective measures and to investigate the safe disposal methods for these protective measures by using the safe, secure and innovative biological methods such as the use of Artificial Intelligence (AI) and Ultraviolet (UV) lights for killing such deadly viruses.

Abbreviations: Adaptive Neurofuzzy Inference System, ANFIS; Antibiotic-resistance genes, ARGs; Antibiotic-resistant bacteria, ARB; Artificial Neural Network, ANN; Biomedical Waste, BMW; Central Pollution Control Board, CPCB; Coronavirus disease 2019, COVID-19; General Packet Radio Service, GPRS; Genetic Algorithm, GA; Geographic Information Systems, GIS; Global Positioning System, GPS; Internet of Things, IoT; Personal protective equipment, PPE; Radio frequency identification, RFID; Remote Sensing, RS; Severe acute respiratory syndrome coronavirus 2, SARS-CoV-2; Support Vector Machine, SVM; Ultraviolet, UV; Very high frequency radio, VHFR; Waste mismanagement, WM; World Health Organization, WHO.

* Corresponding author. Human Molecular Cytogenetics and Stem Cell Laboratory, Department of Human Genetics and Molecular Biology, Bharathiar University, Coimbatore, 641 046, Tamil Nadu, India.

** Corresponding author. Department of Stem Cell and Regenerative Biotechnology, Incurable Disease Animal Model & Stem Cell Institute (IDASI), Konkuk University, 120 Neungdong-ro, Gwangjin-gu, Seoul, 05029, South Korea.

E-mail addresses: ssangoo@konkuk.ac.kr (S.-G. Cho), geneticbala@buc.edu.in, geneticmohana@gmail.com (B. Vellingiri).

¹ Equal contribution.

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1. Introduction

The predicament brought upon by the novel Coronavirus disease 2019 (COVID-19) pandemic has adversely resulted in the global waste generation and hence demands special attention (Balachandar et al., 2020a,b,c; Balachandar et al., 2020a,b,c). This pandemic has caused sudden increase in the demand for personal protective equipment (PPE) such as gloves, masks, and many other important items as hand sanitizers, since, the evidence of individual-to-individual transmission (through respiratory droplets/coughing) and secondary infection of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) (Liu et al., 2020; Balachandar et al., 2020a,b,c). An estimation made by World Health Organization (WHO) projected a requirement of 76 million gloves, 89 million medical mask and 1.6 million goggles per month in response to COVID-19 (WHO, 2020). Pathogenic/infectious waste called as biomedical waste (BMW) and health-care waste is not limited exclusively to health care facilities, medical centers and hospitals only as individuals having mild symptoms also play a key role in the transmission of pathogenic organisms such as virus and/or virus particles. Solid waste management sectors are facing major challenges on the account of increasing waste quantity (Minghua et al., 2009). While the healthcare facilities follows protocols and policies for managing the infectious waste generated, the general public lack the understanding of the disposal protocol to be followed for such waste (Noori et al., 2009; Song et al., 2017; Anila et al., 2020). This negligence might worsen the situation which could even enhance the risk of diseases transmission. In addition, the composition/quantity of these PPEs not only influences different waste generation (especially medical/hospital) but also changes the average density of BMW to the environment. The BMW may also be composed of human anatomical waste, animal waste, microbiology & biotechnology waste, waste sharps, discarded medicines, and cytotoxic drugs, solid waste contaminated with blood, and body fluids including cotton, dressings, soiled plaster casts, linens, beddings, other material contaminated with blood, solid waste generated from disposable items other than the waste sharps such as tubing's, catheters, intravenous sets, and chemical waste (Table 1). In developing countries, where waste management employees are not well equipped with adequate PPEs, the scenario might become even more dangerous and they will be at a higher risk of being infected from virus-loaded waste. Senselessly dumping or throwing these infectious wastes into the environment will impose a risk for being infected to the health of workers engaged in waste management especially in developing countries (Nzediegwu and Chang, 2020). Huge waste generation demands proper segregation according to waste types, collection, and recycling to minimize the risk of infection spread through aerosols and attempts to implement measures to monitor infections (EC, 2020; ACRSRM, 2020; Saar et al., 2004). Waste mismanagement (WM) or unsafe waste (especially biomedical and livestock waste) disposal practices can also result in greater contamination of the environment mostly soil and water ecosystem, development of antibiotic-resistance genes (ARGs) and antibiotic-resistant bacteria (ARB) (Chi et al., 2020; He et al., 2020). A detailed scientific analysis to explore the ability of the existing technologies could provide effective proposition to manage the magnitude of the waste generated in response of COVID-19 (Sudha et al., 2016). Hence, this review focuses on the impact of environment due to improper disposal of these personal protective measures and to investigate the safe disposal methods for these protective measures by using the safe and secure biological methods (Fuchs et al., 2008; Golbaz et al., 2019). Further, in this scenario, the use of environmental informatics could provide an interdisciplinary field where synergistic efforts among environmental science, computer science and electronic engineering aims to tackle specific problems related to environment (Greengard, 2010; Harrington, 2012; Kietzmann, 2008).

Table 1

Various categories of Bio-Medical wastes, its components and treatment.

| Category | Waste components | Waste content | Method of treatment and disposal |
|-------------|---|---|---|
| Category 1 | Human tissues, organs, body parts | Human Anatomical Waste | Incineration/deep burial |
| Category 2 | All types of Animal tissues, organs, body parts carcasses, bleeding parts etc generated by different health sectors | Animal Waste | Incineration/deep burial |
| Category 3 | Wastes from laboratory cultures, stocks or specimens of micro-organisms used in research | Microbiology & Biotechnology Waste | Local autoclaving/micro waving/incineration |
| Category 4 | Needles, syringes, scalpels, blades, glass etc | Waste sharps | Disinfections chemical treatment |
| Category 5 | Out-dated, contaminated and discarded medicines | Discarded Medicines and Cytotoxic drugs | Incineration/ Destruction and disposal of drugs in landfills |
| Category 6 | Blood contaminated cotton, dressings, soiled plaster casts, lines etc | Solid Waste | Incineration, autoclaving/micro waving |
| Category 7 | tubing's, catheters, intravenous sets etc | Solid Waste | Disinfections chemical treatment |
| Category 8 | Waste generated from laboratory and washing, cleaning, house-keeping and disinfecting activities | Liquid Waste | Disinfections by chemical treatment and discharge into drains |
| Category 9 | Ash from incineration of any biomedical waste | Incineration Ash | Disinfections chemical treatment |
| Category 10 | Chemicals used in production of biological | Chemical Waste | Chemical treatment and discharges into drains |

2. Waste adaptation and COVID-19 pandemic

COVID-19 acts as an emerging pandemic disease which is having high mortality and morbidity (Mahalaxmi et al., 2020). To decrease the COVID-19 transmission from human to human, the WHO and other centers involved in the control and prevention of infection have given different rules, such as social distancing, regular washing of hands, and rehearsing appropriate respiratory manners, for example, coughing and sneezing in a flexed elbow. The PPE utilization, for example, facemasks, aprons, and medical gloves have been suggested for fundamental assistance laborers (e.g., specialists, medical attendants, parental figures) and others taking care of patients with COVID-19 infection. A large number of contaminated PPEs (e.g., gloves and facemasks) would wind up as solid wastes, which, if inappropriately oversaw, can present ecological and wellbeing dangers. Recently it was reported (Kampf et al., 2020) that the SARS-CoV-2 can make due on material surfaces such as plastics, glass, and metals for 9 days long. These conditions are protected in developed countries by providing strategies such as green and sustainable waste management. But these conditions are not found in the developing countries where they are dumping solid waste in the open manner and landfills which are managed poorly. The improper management of the produced waste during this pandemic may present serious environmental and health related issues because of the fact that SARS-CoV-2 can survive from several hours to days depending upon the contaminated surfaces (Fig. 1). The potential of viral-loaded waste transmission in developing countries is at higher level because of the improper/poor management strategies. Improperly dumped viral loaded waste may reach to the open lands, where the ragpickers, without proper PPEs, may get exposed and subsequently infected or asymptotically spread the virus (Sarkodie and Owusu, 2020). In Nigeria, a case was reported in which the mortician after burying the

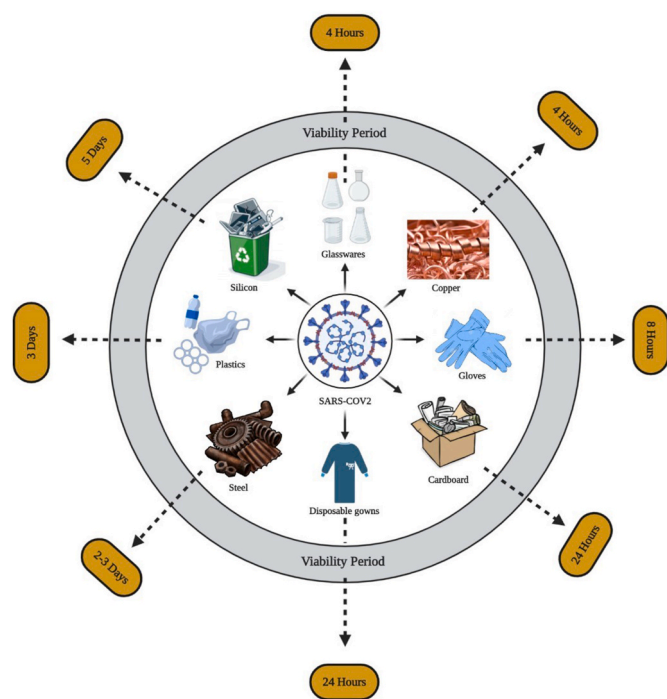


Fig. 1. Survival of SARS-CoV-2 on various substances: This figure represents the survival period of SARS-CoV-2 on various substances. The improper management of the produced waste during this pandemic may present serious environmental and health related issues because of the fact that SARS-CoV-2 can survive from several hours to days depending upon the contaminated surfaces.

body of COVID-19 infected patient discarded his PPE in public area and later the administration took the charge to sanitize the area (Nziedigwu and Chang, 2020). Improper disposal of plastic bottles used in various quarantine and health centers in the developing countries can be a potential source of viral spread and transmission as the bottles may be infected with the virus (Butot et al., 2007). The reuse of infected plastic bottles enhances the risk of viral transmission (Nziedigwu and Chang, 2020). Thus, it is the responsibility of the scientific community to bolster public awareness regarding these potential sources of viral transmission and develop effective waste management strategies to minimize the spread of SARS-CoV-2 and strengthen the global efforts to combat the pandemic.

3. Basic guidelines for Assessment of biomedical waste management

Segregation is the most necessary step of BMW management, as it refers to the primary separation of different categories of waste generated at the basis and thereby reducing the risks as well as the cost of management and disposal. Yellow, Red, Blue/White, and Black color codes are used for the BMW management as per the guidelines provided by BMW Rules, 1998. This consists of placing different kinds of wastes in different containers or coded bags at the point of generation, the colour coding for waste management has been depicted in Table 2. Further in the collection of waste bags a water-proof marker pen is used for labeling the waste bag. They should be labeled with the 'Biohazard' or 'Cytotoxic' symbol as the case may be according to Schedule III of the rules. The containers should bear the name of the department/laboratory from where the waste has been generated so that in case of a problem or accident, the nature of the waste can be traced back quickly and correctly for proper remediation and if necessary, the responsibility can be fixed. After proper collection of waste, it has to be stored in the collection rooms or intermediate storage areas where the waste packets

or bags are collected before they are finally transported to the treatment or disposal site. Further the transport of solid waste constituents of three activities such as the collection of different kinds of waste (from waste storage bags/containers) from various departments of hospitals, transportation and intermediate storage of segregated waste inside the building, and transportation of the waste outside the site (to the treatment/disposal facility). The waste has to be taken to the common storage area first, then from there, it is transported to the treatment or disposal facility, either within or outside the premises. Biomedical waste is transported using trolley. The trolleys are attached with radio frequency identification tags for tracing the trolley movement and should ensure that the transport of waste should be done as per the predefined path only. The transport vehicle should have separate cabins for transporters and biomedical waste. Cabins should be leak-proof and it should be covered, secured against accidental opening of the door, and maybe designed to strong waste containers in tiers. The interior of the cabin should be lined with a smooth finish of aluminum or stainless steel, which can be conveniently washed and disinfected.

4. Safe disposal of waste-the dire need of the hour

In the present pandemic scenario, the WHO has estimated the need of around 89 million masks and 76 million gloves monthly whereas, the global need for spectacles has been proposed to be around 1.6 million units on a monthly basis (Sharma et al., 2020). The individuals with mild and severe symptoms or asymptomatic conditions, with considerable virus-loaded waste present in the trashed masks, tissues, gloves and other safety wearables, present high risk of viral transmission. Since the viral particles can remain viable for hours to days on various surfaces like metal, plastic and cardboards (Fig. 1), the improper handling/disposal of such waste may produce danger among the individuals involved in such waste-handling (Kampf et al., 2020; Van Doremalen et al., 2020). Hence, the COVID-19 waste may cause a community spread and a secondary pandemic, if it is handled inappropriately. The essence of safe disposal is that it will protect the environment and health of people, and save cost. The main reason for the proper disposal of solid wastes is that, if the solid wastes are not disposed of properly, many numbers of bacteria, fungus and virus will grow in the wastes and would lead to epidemic and pandemic outbreaks. Further, these decomposed wastages would release the gases which are further harmful causing pollution in the air. Such conditions might be menacing and hazardous in the developing countries where waste-handling workers due to the scarcity of sophisticated personal protective equipment's. Thus, they are more prone to get exposed to the virus and acquire infection (Sharma et al., 2020). Scientific analysis accessing the efficacy of waste-management protocols during the pandemic could be an important step to regulate safe and efficacious waste-management systems (Klemeš et al., 2020). An extensive estimation before the COVID-19 pandemic revealed that globally around 2 billion people lacked proper waste-deposit facility and around 3 billion people suffered due to the unavailability of regulated waste-disposal system (Klemeš et al., 2020). Therefore, practice of safe and efficacious waste-management protocols has become the biggest challenge for a lot of developing countries amidst the COVID-19 pandemic (Klemeš et al., 2020). Furthermore, scarcity of scientific and technical knowledge and financial support for waste-management system are other major bottlenecks for developing countries during the course of this pandemic (Sharma et al., 2020). In view of this, it is very important to take the necessary precautions to minimize the spread of new infections by proper and hygienic disposal of these BMWs management.

5. Types of the biomedical wastes disposals

5.1. Incineration

This is a high-temperature thermal process employing combustion of

Table 2
Color coded containers for wastes.

| Color code | Type of container | Type of waste | Treatment and disposal options |
|-------------------------------|---|---|---|
| Yellow | Yellow-colored nonchlorinated plastic bags | Human anatomical waste and Animal anatomical waste | Incineration or plasma pyrolysis or deep burial |
| | Yellow-colored nonchlorinated plastic bags | Soiled waste | Incineration or plasma pyrolysis or deep burial. In the absence of above facilities, autoclaving or microwave/hydroclaving followed by shredding/mutilation/combination of sterilization and shredding. Treated waste to be sent for energy recovery |
| | Yellow-colored nonchlorinated plastic bags | Expired or discarded medicines | Expired cytotoxic drugs and items contaminated with cytotoxic drugs to be returned back to the manufacturer or supplier for incineration at temperature >1200° C or to CBMWTF or hazardous waste treatment, storage, and disposal facility for incineration at >1200° C or encapsulation or plasma pyrolysis at 1200° C |
| | Yellow-colored nonchlorinated plastic bags | Chemical waste | Disposed of by incineration or plasma pyrolysis or encapsulation in hazardous waste treatment, storage, and disposal facility |
| | Separate collection system leading to effluent treatment system | Chemical liquid waste | After resource recovery, the chemical liquid waste shall be pretreated before mixing with other waste forms |
| | Nonchlorinated yellow plastic bags or suitable packing materia | Discarded linen, mattresses beddings contaminated with blood or body fluids | Nonchlorinated chemical disinfection followed by incineration or plasma pyrolysis or for energy recovery |
| | Autoclave safe plastic bags or containers | Microbiology, biotechnology, and other clinical laboratory waste | Pretreat to sterilize with nonchlorinated chemicals on-site as NACO or WHO guidelines, thereafter for incineration |
| Red | Red-colored nonchlorinated plastic bags or containers | Contaminated waste (recyclable) | Autoclaving or microwaving/hydroclaving followed by shredding or mutilation or combination of sterilization and shredding. Treated waste to be sent to registered recyclers or for energy recovery or plastics to diesel or fuel oil or for road making |
| Blue/white translucent | Cardboard boxes with blue-colored marking | Glassware, Metallic body implants | Disinfection or through autoclaving or microwaving or hydroclaving and then sent for recycling |
| | Puncture proof, leak proof, tamper proof containers | Waste sharps including metals | Autoclaving or dry heat sterilization followed by shredding or mutilation or encapsulation in metal container or cement concrete; combination of shredding cum autoclaving and sent for final disposal to iron foundries |
| Black | Puncture proof, leak proof, tamper proof Plastic bag | Discarded medicine and cytotoxic drugs, incineration ash, chemicals | Disposal in secure landfill |

the waste under the controlled conditions for converting them into inert material and gases. Incinerators can be oil-fired or electrically powered or a combination of both contents. Broadly, three types of incinerators are used for hospital waste: multiple hearth type, rotary kiln, and controlled air types. All the types can have primary and secondary combustion chambers to ensure optimal combustion which are refractory lined (Gravers, 1998). The multiple hearth incinerators referred

to as air incinerators, due to the presence of the excess air in both of the chambers. In the primer chamber, solid-phase combustion takes place, and gas-phase combustion takes place in the secondary chamber. In the third type of incineration, the first chamber is worked at low air levels followed by an excess air chamber (Tehrani et al., 2017).

5.2. Autoclave treatment

Autoclaving is a process of steam sterilization under pressure. In this procedure, low heat is used in the form of steam for a specific duration into direct contact with the waste material to disinfect. These methods also consist of three types which are gravity type, pre-vacuum type, and retort type. In the gravity type, the air is evacuated with the help of gravity alone, where this system operates with a temperature of 121 °C and a steam pressure of 15ψ for 60–90 min. In the pre-vacuum autoclave system vacuum pumps are used to evacuate air hence the time cycle is reduced to 30–60 min and operates at about 132 °C. Retort type autoclaves are designed to handle much larger volumes and operate at much higher steam temperature and pressure than those of other two types. Autoclave treatment has been recommended for microbiology and biotechnology waste, waste sharps, soiled and solid wastes. Hydroclave is innovative equipment for the steam sterilization process. It is a double-walled container, in which the steam is injected into the outer jacket to heat the inner chamber containing the waste. Moisture contained in the waste evaporates as steam and builds up the requisite steam pressure (35–36ψ). The system operates at 132 °C and 36ψ steam pressure for sterilization about 20 min. The hydroclave used to sterilize waste which can sterilize by the autoclave plus the waste sharps.

5.3. Microwave Treatment

Microwave Treatment is a wet thermal disinfection technology. It provides a high level of disinfection other thermal treatment systems by heating the targeted material from inside out. The input material is first put through a shredder. The shredded material is pushed to a treatment chamber where it is moistened with high-temperature steam. The material is then passed by a screw conveyor beneath a series of conventional microwave generators, which heat the material to 95–100 °C and uniformly disinfect the material during a minimum residence time of 30 min and the total cycle is of 50 min (Thornton et al., 1996).

5.4. Chemical disinfecting

Chemical treatment is recommended for the disinfecting of waste

sharps, solid, liquid wastes, and chemical wastes. Chemical treatment involves the use of at least 1% of hypochlorite solution with a minimum contact period of about 30 min or other equivalent chemical reagents such as phenolic compounds, iodine, hexachlorophene, iodine-alcohol or formaldehyde-alcohol combination (Acharya, 2000).

5.5. Landfilling

Landfilling of biomedical waste can be done by two methods which are sanitary and secured landfilling. Secured landfill is used in the case of the deep burial of human anatomical waste when the facility of proper incineration is not available. Sanitary landfilling may be used for the disposal of autoclaved/hydroclaved/microwaved waste (unrecognizable) and disposal of incineration ash.

6. Innovative methods of BMW management for COVID-19

6.1. Artificial intelligence (AI) in BMW from COVID-19

AI has emerged as a sustainable approach in the era of pandemics of COVID-19 by presenting smart solutions not only in the prevention and diagnosis of the virus but also providing innovative sorting processes in waste management (Król et al., 2016). Proper identification, aggregation, classification, storage, transportation, recycling and disposal, in addition disinfection of the associated waste, personnel protection, and training can be effectively and efficiently managed by implanting AI with the existing technologies such as machine learning and Internet of Things (IoT) (Anh Khoa et al., 2020). To serve this purpose, several models are used such as Adaptive Neurofuzzy Inference System (ANFIS), Support Vector Machine (SVM), Genetic Algorithm (GA) and Artificial Neural Network (ANN), that mimics human traits such as learning, problem solving, understanding, perception, reasoning and awareness of surroundings. AI has been applied in forecasting of waste characteristics which includes waste material classification, waste compression ratio and waste generation, trends or patterns (Younes et al., 2015). Most of the studies use ANNs for automated sorting systems, for e.g., multi-layer ANNs and hyperspectral imaging that identifies different types of waste fraction with high accuracy of 99% (Sudha et al., 2016; Tehrani et al.,

Table 3
Different technologies used for BWM.

| Technologies used in SWM | Methodology Table 3 Different technologies used for BWM | Application | References |
|--|--|--|--|
| Artificial Intelligence | Artificial Neural Network (ANN) | Prediction of bin level status, Waste generation, waste classification, biogas generation, leachate formation, energy recovery, heating value, co-melting temperature of waste, and optimal waste collection routes. | Golbaz et al. (2019); Milojkovic et al. (2008); Noori et al. (2009); Shamschiry et al. (2011); Song et al. (2017). |
| | Adaptive Neuro-Fuzzy Inference System (ANFIS) | Used to forecast the waste generation in such developing countries where accurate reliable data is not always available | Younes et al. (2015) |
| | Genetic Algorithm (GA) | Used for the identification of optimal routes, management costs in the case of MSW collection | Yang et al. (2012); Meyer-Baese et al. (2014); Król et al. (2016) |
| Solid waste Identification | Support Vector Machine (SVM) | Prediction of bin level status, waste generation, classification, waste heating value and energy recovery. | Chen et al. (2016); Harrington (2012); Dixon et al. (2008); Costa et al. (2018). |
| | Barcode | Waste disposal, reduce landfill space, intelligent recycling and risk management | Greengard (2010); Saar et al. (2004). |
| SWM Data Acquisition | Radio frequency identification (RFID) | Bin tracking, sorting and recycling, driver tracking | Ali et al. (2012); Hannan et al. (2015); Arebey et al. (2011). |
| | Sensors | Optimization, waste sorting, odor, moisture and energy measurement | Lewis et al. (1992); Fuchs et al. (2008). |
| Data Communication Technologies | Imaging | Waste sorting, routing and collection, monitoring and optimization | Hannan et al. (2015); Arebey et al. (2011). |
| | GSM/GPRS, VHFR | Long range communication | Ali et al. (2012); Boustani et al. (2011). |
| Spatial Technologies | Bluetooth, Wi-Fi | Short range communication | Chowdhury et al. (2007); Friedlos (2005). |
| | Global Positioning System (GPS) | Vehicle tracking, Route and collection optimization, planning, scheduling | Minghua et al. (2009) |
| | Geographic Information Systems (GIS) | Site selection, planning, estimation, optimization and management | Karadimas et al. (2008); Katpatal et al. (2011). |
| | Remote Sensing (RS) | Site selection, environmental impact assessment, features monitoring | Zhao et al. (2005); Irvine et al. (1997). |

2017). Quantification of useful and harmful by-products is necessary for optimal waste management. Models like ANN and GA are used for predicting composition and quantity of different by-products generated from waste management methods (Ozkaya et al., 2007; Qdais et al., 2010). Waste management strategy also includes waste facility siting, location of waste collection and illegal disposal sites, optimization of cost as well as environmental impacts of accumulation, transportation, treatment and disposal. Various studies employed AI methods to detect illegal waste disposal as well (Fig. 3) (Bautista and Pereira, 2006; Boustani et al., 2011). Another boon of using AI is, when it is combined with robotics, it can revolutionize waste and resource recovery. The combination of robotics, computer vision and AI to detect and separate landfill from recyclables is impeccable. It does this more accurately than human beings, captures high quality waste data and it lets staff know when it's getting full. Thus the use of AI in managing waste generated from such deadly viruses will help the mankind and also to reduce the spread of the disease.

6.2. Ultraviolet rays in BMW management from COVID-19

Another innovative approach towards the proper and hygienic disposal of the COVID-19 related BMWs is the use of ultraviolet (UV) light exposure (Kitagawa et al., 2020; Inagaki et al., 2020). Many studies have approved that the use of UV light exposures is a direct strategy towards killing of antimicrobe's and also its effect against various viruses is said to be promising (Kowalski, 2010; Budowsky et al., 1981). The UV light used to kill or destroy the viruses is a low-pressure mercury-vapor arc lamp which can emit rays of around 254 nm. Also, xenon lamp technology is been used which has the property of emitting UV spectrum lights (Naunovic et al., 2008). The most commonly suggested UV light resource is the far-UVC light which can emit rays between 207 and 222 nm has showed to be efficient against killing the microbes and is also safe to be used by the human beings (Narita et al., 2020; Buonanno et al., 2016; Ponnaiya et al., 2018). It has been reported that UV rays has the ability to disrupt the viral genome by forming pyrimidine dimers and release of reactive oxygen species (ROS) which leads to inhibition of the viral replication (Fig. 3) (Torres et al., 2020; Love et al., 2010; Hamzavi et al., 2020). Hence the use of UV rays for the proper disposal of PPEs which has been used by the COVID-19 patients or health-care worker or by the common people to protect them from this virus should be disposed of by using the UV rays.

7. Waste identification technologies

Waste identification technologies have been widely applied to enhance the automated collection of bins and improve the efficiency of waste management (Table 3).

7.1. Radio frequency identification (RFID)

It is a radio waves-based technology used for automated tracking and identification of an object or assets by transferring information between transponder and transceiver. It has been applied for the supervision of waste collection process by attaching, RFID tag to trash bins and vehicles. By using RFID tag scanner, the SWM operator can accurately check the information regarding bin collection, location of the vehicle driver, time of delivery, etc. With this, it also helps in efficient billing process which promotes the tendency of pay as you throw based billing services (Gnoni et al., 2013; Wylid, 2010).

7.2. Barcode

It is another technology used in waste identification that has contribute significantly in the SWM. It provides an electronic medium which presents data in machine readable form by using geometric codes (Yang et al., 2012). The technology of barcode has been applied to the

range of SWM applications starting from risk management to intelligent recycling of the waste. It helps in the determination of predetermined safety criteria by scanning data from the identifiers associated to the specific type of waste objects and comparing it with the reference data (Maruca et al., 2011). The system of barcode has also been applied to facilitate hazardous waste separation during the collection and treatment of the solid waste generated (Hannan et al., 2015). This technology can provide a way to reduce manual risk determination associated with the waste generated due to COVID-19.

7.3. Data acquisition technologies

In the current time, the applicability of sensors has attained a new momentum showing its humungous usage in acquiring data associated with SWM. A sensor is a device that perceives and deals with several features such as chemical, mechanical or physical properties, and converts these features into signal perceived by other device (Fraden, 2004). Sensors such as Photovoltaic, Mid-infrared sensor and Optical sensors have been used to sort glass containers and ceramic glass waste based upon detecting the colours present on them (Serranti et al., 2006; Van den Broek et al., 1997). Such sensors are also capable to detect recyclable glass containers further minimizing the human contact. In addition, imaging technology is another data acquisition tool which captures and displays the collected information by using different sensors (Meyer-Baese and Schmid, 2014). Spectrometer imaging system has been applied for quick and efficient sorting of plastic waste using near-infrared imaging followed by AI and machine learning based analysis. Another case study has highlighted the usage of digital camera for the sorting of solid waste by image generation and analysis of waste composition (Wagland et al., 2012).

7.4. Data communication technologies

Once the data regarding SWM has been acquired, it is requisite to transmit data for further processing and analysis. To serve this purpose, wireless communication technologies has been opted such as General Packet Radio Service (GPRS) (Faccio et al., 2011) and Very high frequency radio (VHFR) (Lee and Thomas, 2004) for long range communication of solid waste monitoring system (Zhao et al., 2005). For short range communication, technologies such as Wi-Fi (Hong et al., 2014) and Bluetooth (Friedlos, 2005) are used.

7.5. Spatial technologies

Another aspect of environmental informatics is covered by spatial technologies, mainly comprising Global Positioning System (GPS), Geographic Information Systems (GIS) and Remote Sensing (RS) (24). These techniques are specialized in handling complex three-dimensional information and further merge it into various models and interfaces. Its functionality includes capturing, analyzing and storing of the spatial data.

7.6. Global positioning system (GPS)

It is a navigation and global localization system, which has been used in combination of other spatial technologies in SWM system. By applying GPS technology for routing and scheduling of collection vehicles, dynamic scheduling of the vehicle collecting solid waste has been conducted (Wilson et al., 2007). With this, an integrated SWM system was created by applying information and communication technology with GPS to perform collection monitoring and keeping a check on solid waste bin (Arebey et al., 2011).

7.7. Geographical information system (GIS)

GIS is an assimilated tool which permits the amalgamation of various

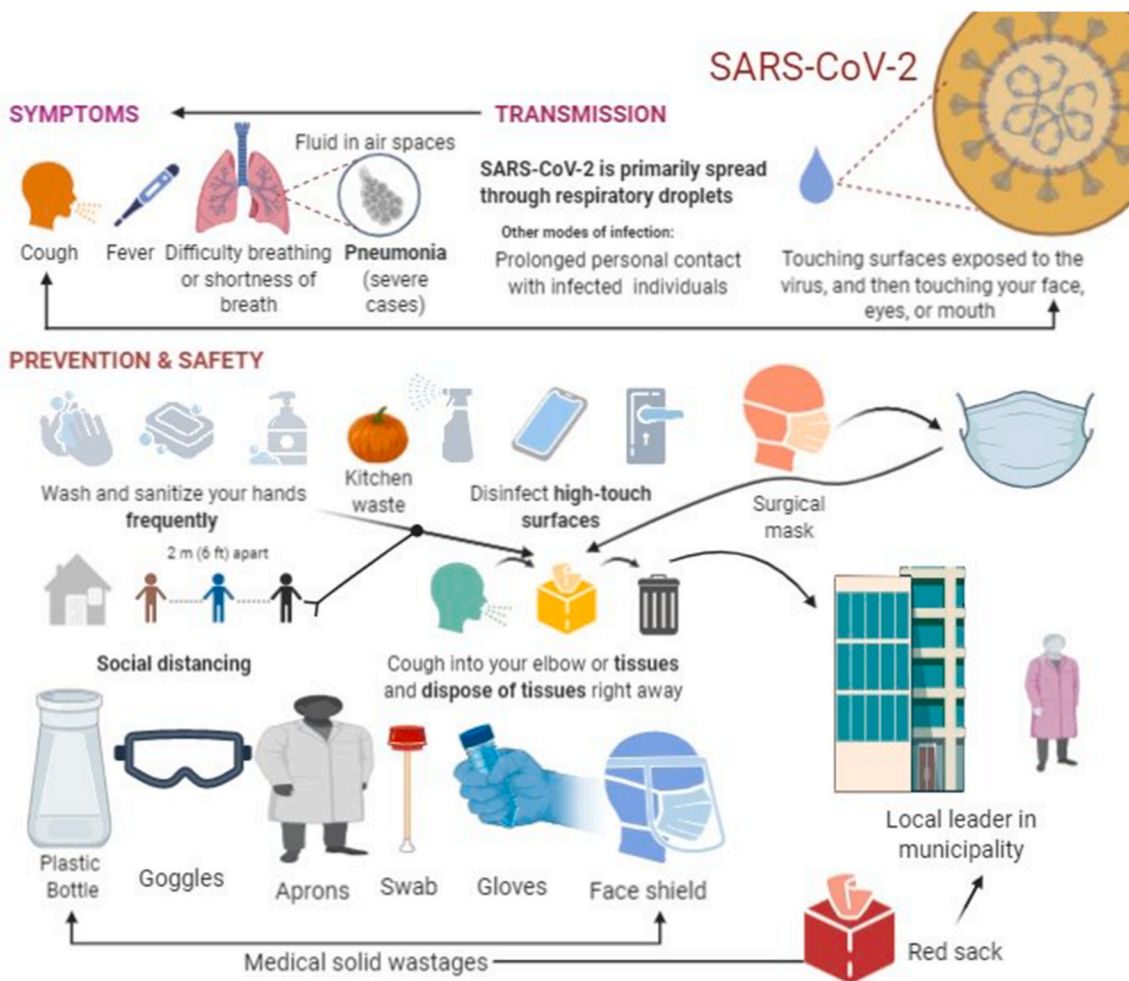


Fig. 2. Impact of SARS-CoV-2 due to improper handling of Biomedical Waste: This figure illustrates the transmission of SARS-CoV-2 virus and the symptoms associated to it. On the other hand it represents the safety and prevention of the infectious disease. For prevention one has to wash and sanitize the hands frequently, disinfect the surfaces and maintain social distancing. The utilized products such as mask, kitchen wastages need to be stored in yellow bag and shifted to local municipal leaders. Medical wastages such as plastic bottles, goggles, aprons, swab, gloves and face-shield should be stored in the red sack and hand-over to local municipal leaders. If this is not done properly, it will increase the transmission of infectious diseases. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

geographical technologies including computer-aided design, automated mapping, Global Positioning System (GPS) and remote sensing to model earth's environmental risk and processes in an accurate manner (Lukashchik et al., 2001; Milla et al., 2005). It can be applied to SWM in four categories i.e., 3D analysis which is applied to sight line analysis and roaming of vehicle routing, spatial analysis which measures spatial distance of an area, surface and buffer analysis and raster interpolation, spatial statistical analysis which combines the spatial analysis with statistical models, and finally, network analysis which uses graphs for depiction (Lu et al., 2013). The analysis undertaken by GIS could be expanded to merge remote sensing images with vector data to estimate current waste generation and predict future generation by building spatial relationship among solid waste characteristics, land uses classes and socio-economic conditions (Karadimas et al., 2008; Katpatal et al., 2011).

7.8. Remote sensing (RS)

Remote sensing is a tool for sensing and categorizing objects on earth surface via propagating a signal by employing aerial sensing technology (Schowengerdt, 2006; Dixon and Candade, 2008). It produces a digital image which can be analyzed together with another spatial data. This technology has been applied widely to perform environmental

monitoring with an aim to observe contamination and recovery standard of the disposed waste (Zhao et al., 2005; Chen et al., 2016). Detection of buried waste for planning site remediation is another facet where RS in combination with aerial image comparison has been applied (Irvine et al., 1997) (Fig. 4).

8. Policy response and implication

Due to the overwhelming tonnes of waste generated during the lockdown, the Government of India, had announced and stipulated various rules and regulation to control and manage the illegal dumping attributed to the COVID-19 crisis (CPCB, 2020). In order to deal with COVID-19 pandemic, State and Central Governments have initiated various steps, which include setting up of quarantine centers/camps, Isolation wards, sample collection centers and laboratories. Following specific guidelines for management of waste generated during diagnostics and treatment of COVID-19 suspected/confirmed patients, are required to be followed by all the stakeholders including isolation wards, quarantine centers, sample collection centers, laboratories, ULBs and common biomedical waste treatment and disposal facilities, in addition to existing practices under BMW Management Rules, 2016. Discarded PPEs from the general public at commercial establishments, shopping malls, institutions, and offices should be stored in a separate

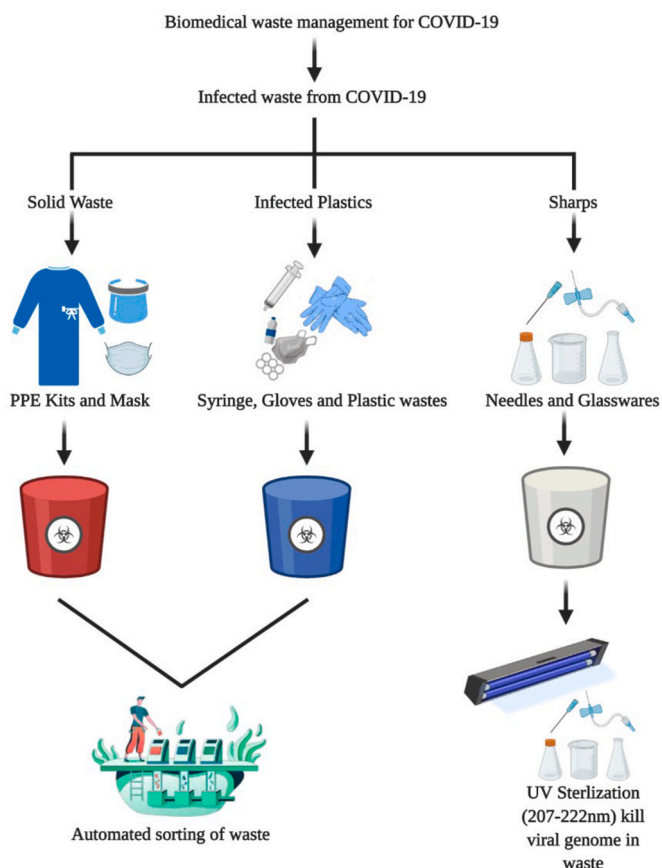


Fig. 3. An Overview of Innovative approach for Biomedical Waste Management: This figure depicts the various colour codes that are used for disposing various biomedical wastes. Further we have showed two innovative approaches to kill SARS-CoV-2 viruses that will be present on the biomedical waste which are the artificial intelligence and ultraviolet lights. These techniques can easily handle and destroy the viruses without further spreading the virus. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

bin for 3 days, thereafter, disposed of as dry general solid waste after cutting or shredding. Waste masks and gloves in general households should be kept in paper bags for a minimum of 72 h prior to disposal of the same as dry general solid waste after cutting the same to prevent reuse. Frequent training are been organized by the Government to education the workers with the modern and well-equipped tools for waste management. Common waste deposition centers are been organized (as stipulated under SWM Rules, 2016) to collect the COVID-19 originated biomedical waste. It has been made compulsory to provide yellow colored bags to the persons operating Quarantine Camp and to care takers of homecare. Proper waste management within the COVID-19 pandemic ensures continuity and functionality of waste services and workers, the safety of waste service workers, adjustments of recycling services to incorporate safety measures that contain the spread in the collection, disposal and treatment of medical waste.

9. Recommendations

- Disposable gloves should be used while performing the disinfection protocols. The waste generated by the disinfection process and all the contaminated materials should be kept in separate containers before the disposal process.
- Utilizing twofold layered packs, compulsory naming, and shading coded receptacles for the administration of waste created during the diagnostics and treatment of suspected and affirmed COVID-19

patients are important for the rules given by the Central Pollution Control Board (CPCB).

- Keep up an independent record of waste created from isolation wards of COVID-19. Utilize devoted trolley and assortment bins in isolation wards COVID-19. A mark 'Coronavirus waste' should be glued on these things. The (internal and external) surface of holders/trolley/ bins utilized for a capacity of COVID-19 waste ought to be purified with a 1 percent sodium hypochlorite arrangement every day.
- The CPCB believed that feces and excreta of COVID-19 patient, who can't utilize latrines, should be gathered in a diaper, considered as biomedical waste, and set in a yellow sack/compartment.
- Gather utilized PPEs, for example, face-shield, goggles, plastic coverall, aprons, nitrile gloves, hazardous materials suit, into a red sack (Fig. 2). Gather utilized mask (N95 mask, triple-layer mask, and so forth.), shoe-cover, head cover, semi-plastic or non-plastic cover all, linen gown in the disposable form in the Yellow sacks.
- The person who is operating the quarantine camps/home cares or centers should hand over the collected solid wastages to the Urban Local Bodies determined by the collector of that area.
- This should be treated with 70% alcohol for decontamination as per the guidelines of NDC, before the usage of herbal medicine and local drink packages.
- Government has to permit those hospitals that are quarantine the COVID-19 patients for the incinerator's facilities to avoid illegal dumping of the solid wastages, contamination of the other solid agents, and transmission of infection.
- Along with that government has to provide IEC material such as Information, Education, and Communication to the public which explains how to properly dispose of the solid waste materials handled by the COVID-19 infected patients.
- All the government should adopt for the new policies urbanized by the Lagos State Waste Management Authority, who has taken the precautions to take the wastages into the landfills.

10. Conclusion

The implication on the solid waste generation in response to COVID-19 has mostly remained undervalued. It has been emphasized that the poorly-managed viral-loaded waste can be highly hazardous and amplifies the risk of viral transmission, primarily in the developing nations. Moreover, due to the imposed lockdowns for longer time-period all over the globe, there are enhanced propensities of generating and accumulating waste products which strongly demand efficient and proper disposal system. In order to limit the spread effectively there is a need to regulate strategies by healthcare administration to properly discard biodegradable and the hazardous/viral-loaded waste products. The mismatch between limited waste collection and excess waste generation during pandemic exacerbates waste management activities. Waste treatment and recycling are affected due to the waste stream prioritization for BMW management during the COVID-19 crisis. However, the challenges imposed on the environment have threatened the prevailing system of managing waste that may magnify the risk imposed on human and environment. Thus, the recent technologies under the spectrum of environmental informatics domain may prove useful in monitoring, assessing, processing and addressing the degradability of the contagious waste generated due to COVID-19. With this, such technologies may also reduce the human intervention by incorporating sensors, imaging and robotics thus can replace the manual sorting of waste. AI embedded in advanced cameras and sensors have also enabled the recycling of solid waste to intelligently recognize and classify the waste, thus overcoming the use and throw tendency which has become prevalent during this pandemic.

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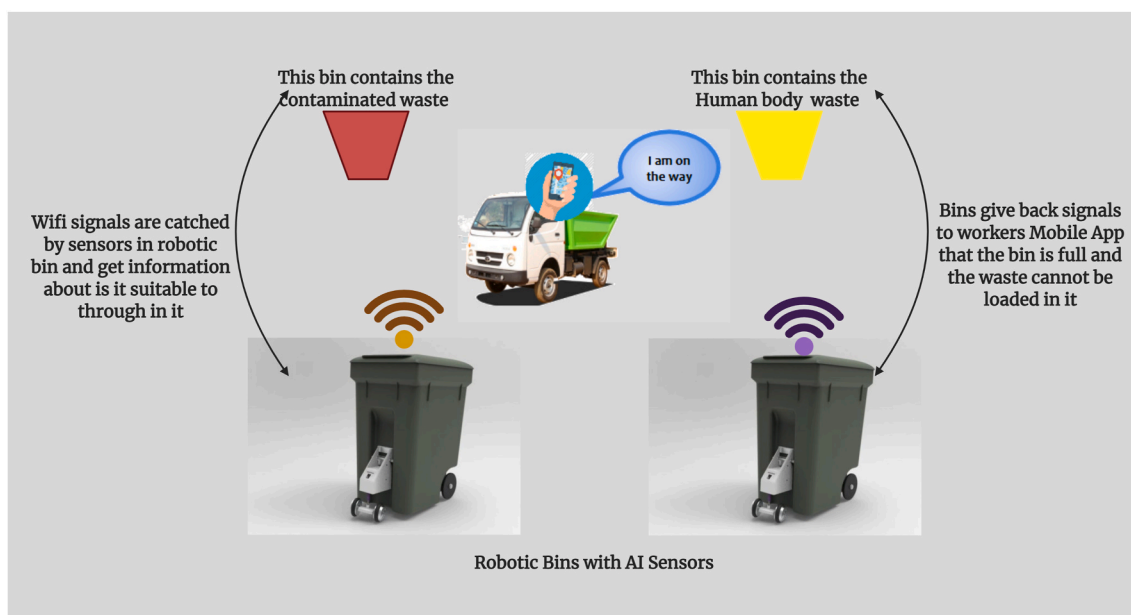


Fig. 4. Use of Robotics and Sensors for COVID-19 waste management: This figure depicts a mechanistic details about the use of robotics and sensors in waste bins to manage the COVID-19 waste management. This picture shows that the sensors in robotic bins would help the worker to detect whether the bin is full or it can be loaded with the waste or using the Wi-Fi which will be enabled in it. This will lead to minimal exposure of workers to the COVID-19 related waste.

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Credit roles

Mahalaxmi Iyer: Data curation, Writing – original draft; Sushmita Tiwari: Data curation, Writing – original draft; Kaviyarasi Renu: Data curation, Writing – original draft; Md. Younus Pasha, Writing – original draft; Shraddha Pandit: Writing – original draft; Bhupender Singh: Writing – original draft; Neethu Raj: Data curation; Krothapalli Saikrishna: Writing – review & editing; Hee Jeong Kwak: Writing – review & editing; Venkatesh Balasubramanian: Conceptualization, Funding acquisition, Project administration; Soo Bin Jang: Writing – review & editing; G. Dileep Kumar: Writing – review & editing; Utpal Anand;; Arul Narayanasamy: Validation; Masako Kinoshita: Validation; Mohana Devi Subramaniam: Project administration, Supervision, Validation, Writing – review & editing; Nachimuthu Senthil Kumar: Project administration, Writing – review & editing; Ayan Roy: Writing – review & editing; Abilash Valsala Gopalakrishnan: Writing – review & editing; Ramakrishnan Parthasarathi: Project administration, Writing – review & editing; Ssang-Goo Cho: Conceptualization, Funding acquisition, Project administration, Validation, Writing – review & editing; Balachandar Vellingiri: Data curation; Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare they have no conflict of interest.

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