WORLD JOURNAL OF PHARMACEUTICAL RESEARCH
SJIF Impact Factor 8.453
Volume 14, Issue 2, 156-172. Review Article ISSN 2277–7105

MEDICAL WASTE MANAGEMENT

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Article Received on 28 November 2024,
Revised on 18 Dec. 2024,
Published on 15 Jan. 2025
DOI: 10.20959/wjpr20252-35185

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ABSTRACT

The collection, segregation, and disposal of medical waste pose challenges for numerous countries. To mitigate risks of harm, illness, and cross-contamination, enhanced measures are essential. Consequently, waste management staff and healthcare workers must comply with mandatory safety protocols. This review discusses the categorization of various types and classifications of medical waste, along with their treatment methods. Due to its potentially hazardous and contaminated nature, medical waste requires careful handling and processing at multiple stages and procedures. Incineration is commonly employed as the primary method for treating medical and hospital waste in various nations. However, it is recognized as a highly polluting process that emits a range of harmful chemicals impacting both the environment and human health. The management and disposal of medical waste in Egypt, China, Germany, and the United States were analyzed as case studies, with a focus on the regulations each of these countries has enacted to oversee medical waste.

KEYWORDS: medical waste; human health; legislations; classification of medical waste; incineration.

1. INTRODUCTION

Several countries, including the US, South Korea, and China, label it as "medical waste," while the World Health Organization (WHO) and the European Union refer to it as "healthcare waste."[1] Healthcare waste (medical waste), according to the World Health Organization (WHO)[2], encompasses any waste or by-products from hospitals and healthcare establishments for humans and animals related to diagnosis, treatment, or immunization, such as used syringes, needles, metal sharps, dressings, blood samples, body parts, pharmaceuticals, chemicals, radioactive materials, and devices. High-income countries typically generate approximately 0.5 kilograms of hazardous medical waste for each hospital bed.[3] The waste generated by the healthcare sector is costly and significantly impacts the environment and public health. Additionally, the generation and disposal of medical waste contribute to pollution and greenhouse gas emissions.[4] Surgical instruments and tools are predominantly composed of polyvinyl chloride (PVC), copolymers, polyethylene (PE), polypropylene (PP), and polyurethane (PU). The first three types of plastics are recyclable and already undergo recycling. As the majority of waste in the operating room is produced before the patient arrives and is neither contaminated nor infected, it can generally be classified as non Hazardous.[5]

Figure: Medical waste management.

Sharma et al.'s review[11] investigated the adverse impacts of incinerating medical waste (MW), focusing on the ash and gaseous emissions. A substantial portion of medical waste (MW) consists of face masks, especially in light of the COVID-19 pandemic and regulations mandating mask usage.

Recent research[6] involving three veterinary clinics, seven hospitals, and medical centers in Massachusetts indicates that plastic waste constituted nearly 30% of the total waste generated by hospitals. Face masks are constructed from non-woven fabrics including polyacrylonitrile, polypropylene, or polyurethane. However, these materials can decompose into small fragments and particles, thus contributing to microplastics. Moreover, the quantity of gloves discarded surged as ordinary people and workers across various sectors utilized latex or plastic gloves for protection during the pandemic. Since these gloves are made from non-biodegradable and non-recyclable materials, improper disposal may lead to environmental harm.[7, 8] Research indicates that greenhouse gas (GHG) emissions associated with the life cycle of plastics represent 15% of total emissions. carbon budget globally.[9] As a result, insufficient management and disposal of plastics threaten the world's ability to meet carbon emission targets and address climate change.[10]

A medium-wave incinerator (MW) emits a variety of pollutants, including fly ash as particulate matter (PM), carbon monoxide (CO), heavy metals (like arsenic, chromium, nickel, cadmium, copper, lead, etc.), acid gases (such as hydrogen chloride, sulfur dioxides, and nitrogen oxides), and organic compounds (including carbon tetrachloride (CCl4), benzene, toluene, xylenes, and polycyclic aromatic hydrocarbons). Leachable organic substances also lead to the formation of ashes and bottom residues that contain dioxins and heavy metals. Additional contributors to the carbon footprint include transportation, autoclave disinfection, thermal processing (i.e., low-temperature incineration at ≥850 ◦C and high-temperature incineration at 1000 ◦C, respectively), and recycling.[12] A UK study indicates significant variability in MW treatment methods. The selection of waste treatment method can affect the carbon footprint by as much as 50 times, as shown by the 1074 kg CO2e/t carbon footprint associated with high-temperature incineration of MW.[12]

A study involving three hospitals in the Netherlands revealed that these hospitals were able to sell refurbished equipment and supplies sourced from their facilities for over 39,000 euros within merely six months. This income could motivate hospitals and the healthcare sector to embrace recycling practices and shift their waste treatment approaches from linear to circular.[13] The current review intends to achieve specific objectives: (i) to classify and categorize the various types of medical waste produced by healthcare facilities; (ii) to detail the processes related to the disposal, segregation, and treatment of MW; (iii) to compare the management and treatment strategies for MW in four different countries worldwide to highlight the least damaging methods, thereby aiding decision- makers in the health sector and industry in making more informed choices; and ultimately, to demonstrate the impact of the COVID-19 pandemic on waste volumes and its consequences.

2. Classification of Medical Waste

The WHO estimates that 15–20% of medical waste is classified as hazardous materials due to their toxicity, radioactivity, and infectivity.[14,15] However, since this classification is not entirely straightforward or definitive, medical waste disposal practices vary widely across different nations.[16]

Infectious, toxic, or other hazardous waste (HMW), as illustrated in Figure 1 and characterized with examples in Table 1, pertains to medical waste when it is used directly or indirectly. Specifically, medical facilities generate infectious, pathogenic, harmful, pharmacological, and chemical waste during medical or preventive care and related operations.[1] Conversely, all other general, non- infectious waste elements, such as municipal solid waste, fall under non-hazardous medical waste (NHMW). HMW is usually contaminated with pathogens. Hence, improper application or negligent handling and disposal can lead to various infections and diseases. Furthermore, it can result in environmental pollution through mishandling, affecting soil, water, plants, animals, and air and potentially causing disease spread. The quality of life for patients, healthcare workers, and their physical and mental well-being can all be jeopardized by MW.[18] Approximately 20% to 30% of MW consists of plastic.[19]

Types of waste management

1] Infectious waste

It is hypothesized that infectious wastes contain pathogens like bacteria, viruses, parasites, or fungus that, when present at sample amounts, cause diseases in susceptible hosts. Microbial cultures, infectious agent stocks from pathological labs, and waste products from procedures performed on infected patients (such as disposable towels, gowns, aprons, gloves, etc.) are also included.

2] Sharpes waste

Any medical instrument that has the ability to pierce the skin of humans or animals is considered a sharp. Sharps are commonly utilized in medical settings, particularly for IV insertion, blood collection, and introduction They are disposed of in containers that are specifically designed for them.

3] Radioactive Waste

Biomedical wastes that contain radioactive materials include undesired radionuclide solutions meant for use for medical or therapeutic purposes, spill trash, and breakdown of radioactive leaks.

4] Pharmaceutical Waste

Unused, spilled, and contaminated pharmaceutical products , such as vaccinations and sera that are no longer in use, as well as expired medications more frequently used items should be disposed of in an in a suitable way. Waste from pharmaceuticals may also comprise materials used for packaging that come into contact with the pharmaceutical items such aluminum packets, glass bottles, etc.

Pharmaceutical Waste Origins

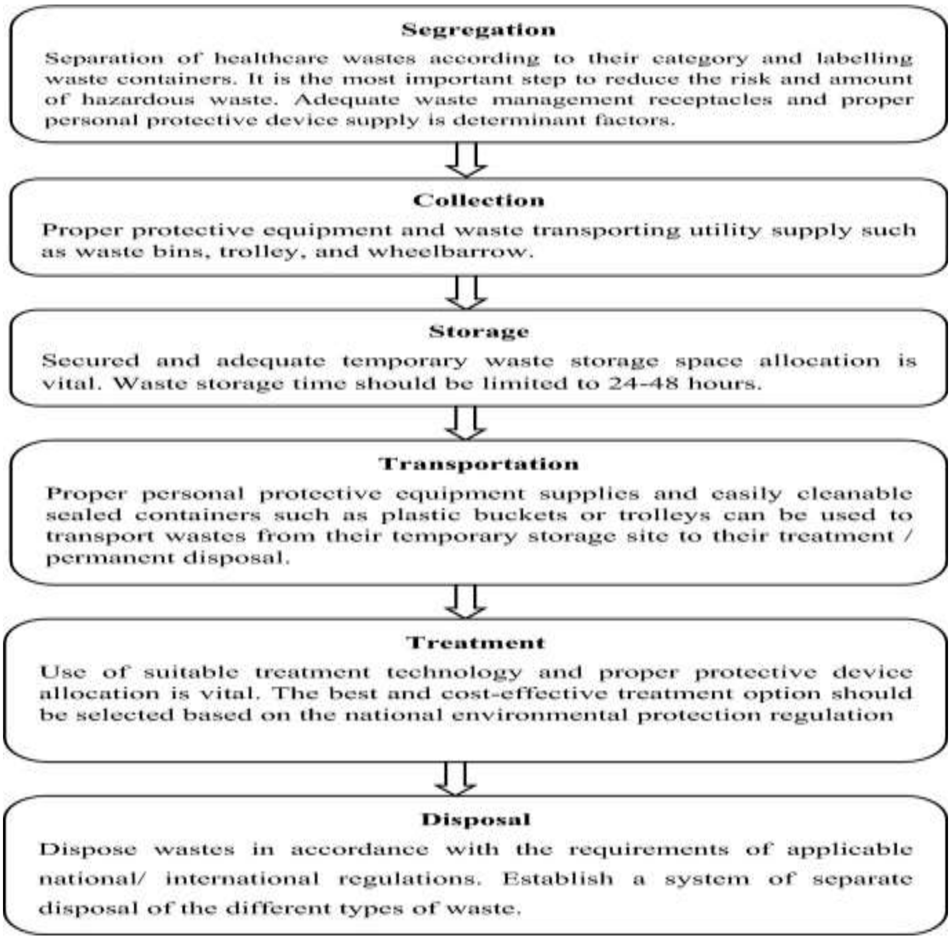
Despite being in the environment for decades, pharmaceutical wastes have been measured. recently by the scholars.

1. Medical and pharmacological waste
2. Disposal of pharmacy waste
3. Waste from the home that includes expired and unused medications .

4. Drug leaching from defective landfills
5. Improper and direct disposal of expired or unneeded patients' prescription drugs into the trash and also by fecal or urine discharge.
6. Substances discharged from aquaculture and other sources Molecular farming, medicated feed, and pest management medications, etc.
7. Even in numerous emerging nations, such as India, the examples of physicians provided by businesses to medical representatives with the purpose of promoting sales goal.

3. Medical Waste Management Procedure

The procedure for overseeing medical waste includes handling it from the moment of generation until its safe disposal. Figures 2 and 3 illustrate the steps in the medical waste management procedure. The realization of a circular economy, in which resources used within the healthcare sector are maximized and nearly no waste is created, along with the decrease in waste heading to landfills, demonstrates the efficiency of the waste management procedure.



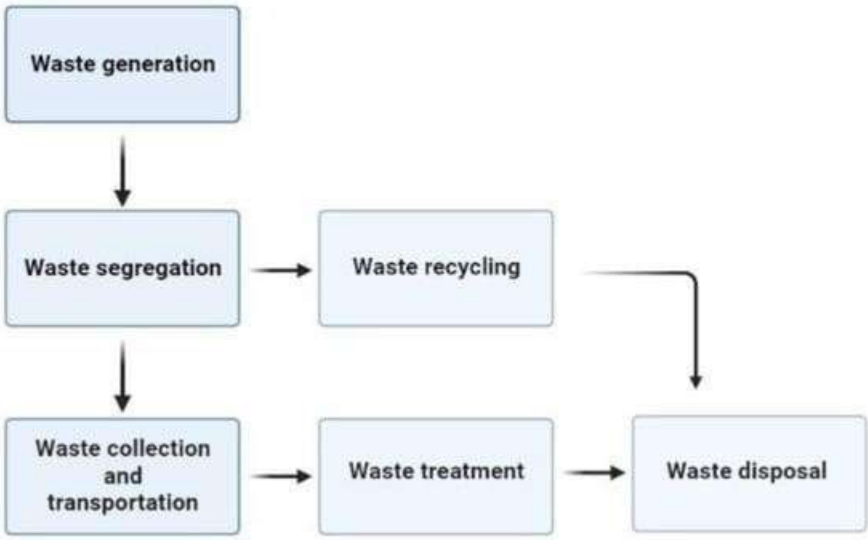


Figure: Flow scheme for medical waste management.

3.1. Waste Generation

As mentioned in the previous section, there are various categories for the medical waste that is produced. The quantity of waste generated and its management to ensure protection for workers who encounter it are vital components of this process. Reduction of waste from healthcare facilities is possible to diminish the buildup of refuse. There are numerous strategies for minimization, including inventory management, recycling, and source reduction. Recycling items that pose no harm to users, such as washable tablecloths, utensils, and refillable containers for cleaning agents, can aid in decreasing waste at the source.[20] Composting organic waste and recycling metals and plastics can contribute to waste reduction. Finally, effective inventory management will help establish an organized system for the stock of medications to prevent excess and the purchase of unnecessary items that could expire, thus potentially reducing waste.[20]

3.2. Waste Segregation

Waste is categorized based on its type and gathered through segregation methods. The main approach to segregation involves sorting the various types of medical waste into bins or bags of distinct colors assigned to each category.[20] The absence of uniformity in the colors linked to each waste category can lead to complications when collecting from different sources.[15] This extends the time and expense required for labor and equipment to separate the waste and guide it to the correct waste stream. Segregation should primarily happen at the point of origin, except for waste that undergoes the same treatment process, which may be segregated at the treatment facility.[20] It is essential to separate sharp objects at the source[20] Medical staff conduct the segregation, and they must be trained in appropriate waste disposal methods to avert infections.[15] An error made during waste segregation should not be rectified to prevent contamination of other refuse.[20] Medical waste must be handled securely to prevent unauthorized human contact, which could lead to diseases.[15]

3.3. Waste Collection and Transportation

To avoid waste accumulation, which can spread diseases, the collection of medical waste should occur as often as once daily. Additionally, to prevent contamination and illnesses, those responsible for collection should wear protective attire that can be disposed of properly after use.[20] The waste is collected from the healthcare facility and transported to the treatment center for disposal, recycling, and processing. Treatment facilities may be located off-site at a different location or within the healthcare facility itself.[15]

3.4. Waste Treatment

Before disposal, medical waste must undergo treatment to minimize its potentially detrimental effects on the environment and human health. The following are some consequences that inadequate treatment may lead to.[21]

- Poisoning due to hazardous substances,
- Infections from bacteria and fungi,
- Emission of toxins into the air,
- Contamination of soil and underlying aquifers,
- Bioaccumulation,
- Impact on the environment,
- Damage to ecosystems.

Whenever medical devices are produced, it is crucial to consider their impact through a life cycle analysis (LCA) and to implement suitable treatment methods. Conversely, the treatment processes and techniques have minimal influence on the quantity of carbon emissions released into the atmosphere. For example, during the disposal stage, a single intravitreal injection generates an emission of 0.05 kg CO2e.[22]

Table 2: presents various medical waste treatment options along with their primary benefits and limitations. Despite these challenges, these methods can reduce the aforementioned risks. Currently, the industry employs incineration, chemical and mechanical disinfection, autoclave disinfection, and microwave disinfection.[21]

Table 2: A comparison between treatment methods in terms of advantages and disadvantages.

Treatment Method	Advantages	Disadvantages
Incineration	– Weight and volume reduction – Suitable for all waste types – Heat recovery	– Emissions, e.g., furans and dioxins – Public opposition – High capital and operating costs – High maintenance costs – Restrictions due to emissions regulations
Autoclave disinfection	– Low operation costs – Adequacy for biological testing – Less hazardous residues	– No change in waste characteristics – Inapplicable for all waste types – Unknown air emissions
Microwave disinfection	– Volume reduction – No liquid discharge	– High capital cost – Weight increase – Inapplicable for all waste types – Risk of exposure – Unknown air emissions
Chemical disinfection	– Volume reduction – Time efficient – Removal of waste odour	– High capital cost – Inapplicable for all waste types – Unknown air emissions – Storage and handling of chemicals

3.4.1. Incineration

As incineration can be utilized for any type of waste, it is the most frequently employed treatment method.[23] Incineration occurs in furnaces operating at temperatures between 800 and 1200 °C.[23] The high temperatures eliminate pathogens while also destroying 90% of the organic matter and modifying the waste's weight, volume, and form.[23] This process is influenced by several factors, including.[21]

- Waste mixing,
- Moisture levels,
- Quantity of waste in the furnace,
- Temperature,
- Residence time,
- Maintenance and repairs.

During incineration, fly ash and contaminants such as furans, dioxins, and mercury are emitted.[23] Dioxins and furans are long-lasting environmental pollutants with a half-life of 7 to 11 years and are considered carcinogenic.[23] Complete combustion of waste can help reduce dioxin emissions.[23] A further technique for addressing the released dioxins is selective non-catalytic reduction (SNCR).[24] This method involves producing free nitrogen through the interaction of ammonia and nitric oxide, resulting in a gas that is both cost-effective and highly efficient.[24] Mercury, which has detrimental effects on the neurological system and overall health, constitutes 3-9% of the emissions from incineration.[23] The solid residue that contains significant amounts of heavy metals is referred to as fly ash.[25] Burning one kilogram of clinical waste generates approximately three. kilograms of CO_2, burning medical waste (MW) generates a significant amount of greenhouse gases (GHG), mainly CO_2.[26] This contributes to the role of MW in global warming.

3.4.2. Autoclave Disinfection

Steam and heat collaborate to eliminate microorganisms during autoclave disinfection.[15] To achieve disinfection, it operates at a temperature lower than that of incineration while still employing steam and pressure.[20] To ensure complete waste disinfection, the operational parameters are set to 60 minutes at 121 °C and 1 bar, followed by another 60 minutes at 134 °C.[20] The operation of the autoclave is influenced by the following factors.[21]

- Temperature (121–134 °C),
- Steam penetration,
- Waste load,
- Duration of the treatment cycle,
- Chamber air removal.

The waste must undergo pre-treatment through incineration prior to landfill disposal as the low operating temperatures in autoclaving do not change the waste’s appearance or eliminate pathogens.[15] Thus, not every type of waste is ideally suited for the autoclave.

3.4.3. Microwave Disinfection

Microwave disinfection utilizes low temperature and strong microwaves to break down organic matter and microorganisms through reverse polymerization.[23] This method is more environmentally friendly since the waves induce vibrations in molecular bonds, conserving energy and preventing emissions.[23] It employs electromagnetic waves with wavelengths from 1 mm to 1 m and frequencies ranging from 300 to 3000 MHz to disinfect at temperatures between 177 and 540 °C.[23] Microwave disinfection can be integrated with autoclaving and incineration, although it is quite costly.[23] This method's operation is influenced by the following factors.[21]

- Waste properties,
- Moisture content,
- Microwave intensity,
- Exposure duration,
- Level of waste mixing.

3.4.4. Chemical Disinfection

Chemical disinfection employs chemicals to fight infections and eradicate microorganisms.[20] It is used for treating liquid pathogenic wastes such as blood, urine, feces, and hospital sewage.[20]

Commonly used chemical disinfectants include a 1% bleach solution and a 0.5% diluted active chlorine solution.[20] Other possible disinfectants are peracetic acid, ozone, lime, and ammonium compounds.[20] This treatment method has immediate effects on personnel managing the process due to the inhalation of volatile chemicals or skin and eye irritations.[20] The efficacy of this approach is influenced by the following factors.[21]

- pH,
- Contact duration,
- Waste and chemical interaction,
- Recirculation versus flow.

Both liquid and solid residues are produced after this process.[23] Solid residues are disposed of in a landfill, while liquid byproducts are directed to the sewage system.[23] Determining the waste characteristics, type, and intended outcome is the initial step in selecting an appropriate treatment method. These attributes should be evaluated against each treatment option to highlight the advantages and disadvantages of every procedure.[21]

3.5. Waste Recycling

Recycling waste consists of repurposing generated garbage or byproducts either for reuse or in novel applications. The majority of waste produced in the medical field is non-hazardous, primarily sent to landfills. Recycling items like plastics, batteries, paper, glass, metals, and silver from photographic processing can reduce the reliance on dumps and landfills.[20] Composting is feasible with food and organic waste.[20] Fly ash resulting from incineration can be repurposed as construction materials and in concrete mixtures once treated.[25] The heat generated by incineration can be utilized to warm water for central heating systems.[20]

3.6. Waste Disposa

The byproducts from the earlier processes are transported to a sanitary landfill for disposal. However, due to their detrimental environmental effects, landfills are not the optimal solution for processing MW. These effects include contamination of land and water from leachate and gas emissions into the atmosphere from waste decomposition.[23] Therefore, minimizing waste disposal is essential, and a circular economy promotes this. The primary method for landfill waste disposal is through prolonged decomposition.[23] To ensure the safe disposal of MW, the following precautionary measures should be taken.[20]

- Quick coverage of waste,
- Burying under a minimum of three months of old municipal waste.

4. Management of MW in India

The initial set of regulations for tracking and managing medical waste was published by the Indian Ministry of Environment and Forests in 1998. These regulations have since been revised multiple times. In an effort to reduce environmental pollution, the Ministry of Environment, Forestry, and Climate Change amended the legislation in 2016. The coverage was broadened, the authorization and classification processes were streamlined, and disposal, transportation, and segregation methods were improved, along with stricter emission standards (capping suspended particulate matter emissions from incinerators at 50 mg/nm3).[27] Approximately 0.5–2.0 kg of waste per bed per day generated a total of 0.33 million tons of medical waste annually in India.[28]

5. COVID-19 and Medical Waste

Globally, most nations observed a substantial reduction in air pollution and greenhouse gas emissions during the early months of the pandemic, largely due to the restrictions on numerous human activities. In contrast, the production of medical waste from discarded equipment and materials, such as various plastic containers, test kits, gowns, and syringes, rose significantly following the COVID-19 outbreak and the initiation of vaccine production and distribution.[29]

In China alone, a nearly 24% increase in MW generation was reported, reaching over 6000 tons at its peak in 2020. Another study found that during the COVID-19 crisis in China, MW volumes dropped by up to 30% in medium and large cities; conversely, the quantity of MW with high plastic content surged by approximately 400% in Hubei province.[30] Furthermore, Wuhan generated more than 240 tons per day of MW following the onset of the pandemic, exceeding the pre-pandemic average by 190 tons.[31]

Medical waste and waste from personal protective equipment usage, particularly after the COVID-19 pandemic, are regarded as potential sources of infective spread. For example, the MW rate attributable to the Coronavirus in Wuhan, the epicentre of the pandemic, escalated from 0.6 kg/bed/day to 2.5 kg/bed/day.[32] In Bangladesh, the increase in plastic pollution has been drastic due to heightened plastic waste generation following the COVID-19 outbreak, which led to more than 14,000 tons of biological and medical waste being produced compared to about 200 tons per day prior to the virus.[33] A study evaluating the waste situation, including biomedical waste, after the COVID-19 outbreak indicated that not only did MW generation from healthcare facilities rise during the pandemic, but all waste could also be considered infectious due to the high incidence of COVID-19 cases recorded. Moreover, as the virus spread worldwide at different intervals, coupled with its high transmissibility, the risk of cross-contamination and disease spread significantly increased.[34]

From a practical standpoints, Voudrias explored five different medical waste treatment methods, such as chemical disinfection, steam disinfection, microwave disinfection, reverse polymerization, and incineration. The objective was to identify the most effective method using multicriteria analysis. In assessing these technologies, the author proposed employing the analytic hierarchy process, which emphasizes environmental, economic, technological, and social factors as essential evaluation criteria. The author set forth sub-criteria for the environmental aspects: emissions of greenhouse gases, environmental impacts of air emissions, solid waste, and liquid residues, energy and water consumption patterns, volume reduction, and effective microbial inactivation.[35]

CONCLUSIONS AND RECOMMENDATIONS

Approximately 75% of medical waste (MW) is non-hazardous, constituting a significant part of the total waste generated in most countries. The remainder is classified as hazardous due to the presence of infectious agents that can transmit diseases and cause various health issues; therefore, it is essential for MW to be managed and processed properly. Incineration is considered the most commonly utilized method for treating municipal waste (MW) globally, and improved management can be achieved through appropriate (local) laws and regulations to minimize the risk of cross- contamination and decrease pollution levels during the recycling and treatment of this waste type. Additionally, the COVID-19 pandemic resulted in a marked increase in medical waste (MW), particularly concerning personal protective equipment (PPE), which encompasses gowns, masks, and syringes used for vaccinations. Given their low biodegradability and potential to harm the environment, PPE demands special handling.

Several factors must be considered to enhance MW management and treatment, increase its efficiency and sustainability, and reduce production, disposal, and treatment costs.

(i) the use of materials and disposable products should be regulated to decrease waste generation;
(ii) waste should be sorted more rigorously and carefully according to regulations.
(iii) incineration should be restricted.
(iv) stricter technological measures, like filtering and treating emissions from incinerators;
(v) investment in innovative eco-friendly technologies for MW disinfection and treatment.
(vi) the development of more easily degradable materials for the production of personal protective equipment.

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