Review Article

MEDICAL WASTE MANAGEMENT: TREATMENT, RECYCLING AND DISPOSAL OPTIONS

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Abstract

Medical waste (MW) is all waste generated in healthcare institutions during the provision of healthcare services, conducting scientific research and experiments in the field of medicine, regardless of its composition and origin, i.e.. a heterogeneous mixture of classic municipal waste and hazardous MW. Medical systems including hospitals, clinical centers, and places where diagnosis and treatment are conducted generate waste that are highly hazardous and put people under risk of fatal diseases. In general, MW does not take up much of the environmental pollution, but its specific characteristics are potentially among the most dangerous types of waste. Inadequate care can affect the health of the medical workers, the population, and the surrounding areas in which the waste is stored, but also lead to outbreaks of global infection and poisoning. However, extra caution is required to avoid the risk of injury, cross-contamination, and infection; thus, healthcare workers and individuals responsible for waste management must follow the mandatory safety procedures. In this review, a classification of the various types and categories of MW and its treatment methods are discussed. Since MW

can be contaminated and hazardous, it must be managed and processed using complex steps and procedures. The meaning of MW, the risks of exposure, MW management regulatory acts, MW management procedures and control techniques are presented.

Keywords: medical waste, individual health; legislation

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Introduction

Medical waste (MW) is limited to infectious, hazardous, and any other waste that are generated from health care institutions, such as hospitals, clinics, dental offices, and medical laboratories[1]. The management of MW has been of major concern due to potentially high risks to human health and the environment.

The World Health Organization (WHO) defines MW as any waste or by-products from hospitals and health care facilities for humans and animals used for diagnosis, treatment, or immunization, e.g., used syringes, needles, metal sharps, dressings, blood samples, body parts, pharmaceutical, chemical, radioactive materials, and devices[1]. Generally, countries with high revenue generate up to 0.5 kg/hospital bed of hazardous medical waste[2]. The health care sector's waste extensively impacts the environment and public health, proving very costly.

Hassan et al., 2008 report a survey on Bangladesh hospitals that generate a total of 5562 kg/day of waste, of which about 77.4% are non-hazardous and about 22.6% are hazardous. The average waste generation rate for the surveyed hospital is 1.9 kg/bed/day or 0.5 kg/patient/day. In Bangladesh, proper medical waste management is a new phenomenon and

government of Bangladesh is trying to develop a new and modern approach to deal with the MW properly[2].

The manufacturing and discarding of medical and health care sector waste leads to increased levels of greenhouse gases emissions and pollution[3]. The types of plastics that are mainly used to make operating room tools and equipment are polyvinylchloride, polyethylene, polyropylene, polyurethane, and co-polymers. The first three types of plastics can and are being recycled. In general, most of the operating room's waste can be considered non-hazardous because it is generated even before the patient arrives and is not contaminated or infected[4]. The use of hand gloves made of latex or plastic for protection by ordinary people and workers in various sectors after the pandemic led to an increase in the amount of disposed of gloves. In addition, gloves also contribute to pollution of the environment when disposed of improperly because they are made of unrecyclable and undegradable materials[5,6]. A study highlighted that 15% of the total global carbon budget is attributed to the greenhouse gases emissions resulting from the life cycle of plastics[7]. Therefore, poor management and disposal of plastics threaten the ability of the global community to meet carbon emissions targets and combat climate change [8].

A vast variety of pollutants are released from a MW incinerator, including fly ashes as particulate matter, carbon monoxide, heavy metals, e.g., arsenic, chromium, nickel, cadmium, copper, lead, etc., acid gases such as sulfur dioxide, nitrogen oxides, and hydrogen chloride, organic compounds such as carbon tetrachloride, benzene, toluene, xylenes, and polycyclic aromatic hydrocarbons. In addition, leachable organic compounds form bottom residues and ashes containing heavy metals and dioxins. In addition, there is the carbon footprint of transportation, autoclave decontamination, thermal treatment (i.e., low and high temperature

incineration at 850 Cº and 1000 C°, respectively), plus the carbon emissions produced during recycling[9,10,11].

The specific objectives of this review are as follows: (i) to classify and categorize the different types of MW generated from healthcare facilities, (ii) to outline the steps and processes involved in the disposal, segregation, and treatment of MW, (iii) to compare the practices for management and treatment of MW in clinical centers of Serbia and define the least deleterious methods and, thus, help decision-makers in the health sector and industry to make better choices, and, finally, to demonstrate the impact and consequences of the COVID-19 outbreak on the amounts of MW".

The objective of this paper is to inform readers about the MW management regulatory acts, definition of medical waste, risks of exposure, MW management procedures and control techniques.

Medical Waste -Definitions

WHO has classified MW into different types: a) Infectious: material containing pathogens in concentrations high enough to cause diseases on exposure. This includes waste from surgery, lab cultures, used dressings, and others. b) Sharps: disposable needles, syringes, blades, broken glasses. c) Pathological: tissues, organs, body parts, human flesh, blood, and body fluids. d) Pharmaceuticals: drugs and chemicals that are returned, spilled, expired, or contaminated. e) Chemical: waste resulting from diagnosis, or cleaning material. f) Radioactive: waste contaminated with radioactive substances used in diagnosis and treatment of diseases. g)

Pressurized containers including gas cylinders; and h) Substances with high heavy metal content: broken mercury thermometers, blood pressure gauges. Infectious, pathological and sharps are the most dominant types of MW [12].

The definition of MW excludes waste containing microbiological cultures used in food processing, urine, saliva, and nasal secretions unless they contain blood. Like any household and office, medical facilities also generate general waste such as paper and plastic that are not dangerous to human beings[13]. Medical waste such as sharps (*i.e.*, needles, syringes, scalpels, etc.) can endanger humans in a non-infectious way. Regardless of its quantity and where it is generated, MW has serious sometimes fatal effects on exposure. Medical staff, janitors, medical center visitors and patients are exposed to the risk of infection and diseases because of exposure. Thus, MW hazards and risks exist not only for the waste generators and operators, but also for the general community including children who play near disposal areas. The possible exposure pathways include direct contact, airborne transmission, contaminated water sources and the environment in general. The Medical Waste Tracking Act (MWTA, 1988) is the first act to regulate MW[14]. It was implemented after life-threatening incidents occurred due to the lack of proper MW disposal systems. One example of such an incident was in June 1987 when 12 children in Indianapolis, Indiana, played with vials they found in a dumpster outside a medical office. The vials were filled with blood, and two of them were infected with AIDS. After MW was found washing up on several East Coast beaches, USEPA (US Environ-mental Protection Agency) prompted US Congress to enact the MWTA in 1988[15]. The Act required EPA to create a two-year MW demonstration program.

Classification of Medical Waste

According to estimates by the WHO, 15 to 20% of MW can be classified as hazardous materials due to their infectivity, toxicity, and, sometimes, radioactivity[16,17]. MW refers directly or indirectly to infectious, toxic, or otherwise hazardous waste (HMW), illustrated in Figure 1 and described with examples in Table 1. Medical institutions generate this type of waste during medical or preventative care and related activities, specifically infectious, pathological, damaging, pharmaceutical, and chemical waste[18]. On the other hand, non-hazardous medical waste (NHMW) includes all different regular non-infectious fractions of waste, such as municipal solid waste. HMW is usually contaminated with pathogens. Therefore, it can cause a wide range of infections and diseases in the case of misuse or poor handling and discarding. Adding to that, it can cause environmental contamination in the case of poor management, causing pollution to land, water, plants, animals, and air, leading to the spread of diseases.

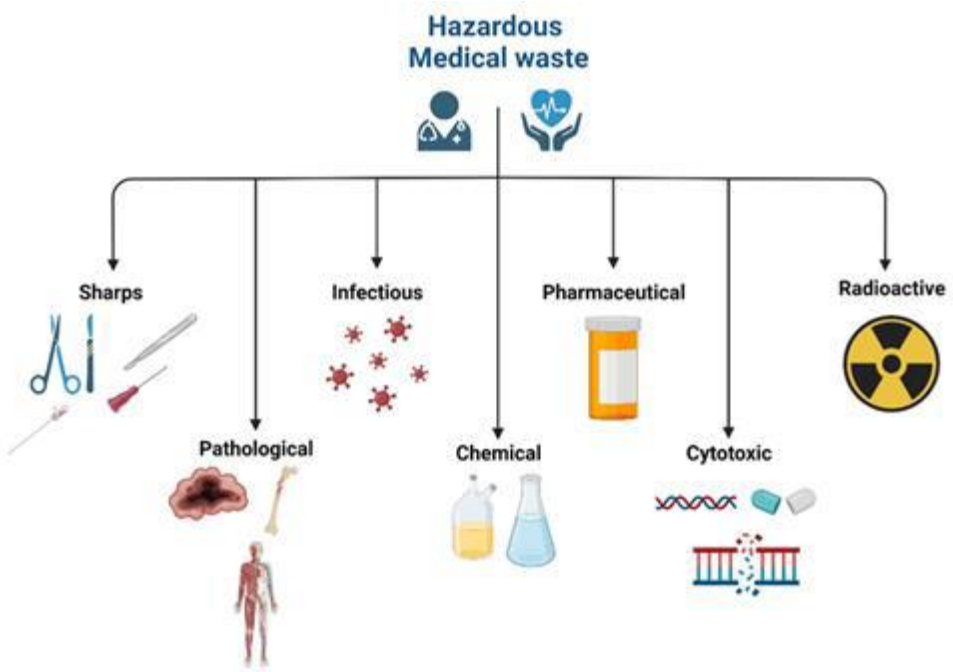

Figure 1. Different types of hazardous medical waste

Table 1. Healthcare waste categorization according to WHO and the EU [19,20].

Category	Examples	WHO	EU	Source
	Sharps	Sharps	Sharps	Hospitals, clinics, laboratories, blood banks,nursing homes, veterinary clinics and labs
	Organic matter, including. body parts and blood	Pathological	Human tissue, body parts, organs, and blood preserves and bags	Hospitals, clinics, laboratories, mortuary and autopsy facilities, veterinary clinics and labs
Hazardous	Waste with restrictions in collection and disposal due to infectivity	Infectious	Human and Animal Infectious	Hospitals, clinics, and laboratories

	Waste with no restrictions or special requirements for collection and disposal due to infectivity (e.g., plasters, casts, dressings, bed sheets, disposable clothing, etc.)	Infectious	Infectious	Hospitals, clinics, and laboratories
	Dangerous chemical materials and substances	Chemical	Chemical	Hospitals, clinics, and laboratories
	Other chemicals	Chemical	Chemical/ Unused hazardous medicines	Hospitals, clinics, and laboratories
	Cytotoxic and cytostatic medicines	Cytotoxic	Discarded unused medicines	Hospitals and laboratories
Nonhazardous	Other chemicals (non-hazardous)	Pharmaceutical	Unused nonhazardous medicines	Hospitals, clinics, and laboratories
	Dental clinics (care centers) amalgam waste	Amalgam (tooth filling) waste from dental clinics/centers	Amalgam waste from dental clinics/centers	Dental care centers and clinics

Medical Waste Management

MW management is a series of steps where the MW generated is handled from the generation point until it can be disposed of safely.

Waste Generation

The critical aspect of this step is the amount of waste produced and how it is handled to prevent hazards to the personnel in contact with it. The waste generated from medical institutions can be minimized to reduce waste accumulation. The minimization can be approached from different directions, such as reduction in waste at source, recycling, and stock management.

Waste Segregation

Segregation is useful since it prevents the contamination of non-hazardous waste by the hazardous waste and making the whole waste stream hazardous. Thus, this method will reduce the toxicity and the volume of the waste stream. Moreover, segregation makes it easier to transport the waste. Waste is segregated depending on the quantity, composition, and the disposal method of the waste stream. Segregation is mainly achieved by separating different categories of MW in different color bins or bags specified for each category. The sharp objects should always be separated at the source[21]. The segregation is carried out by medical staff, which requires training to safely dispose of waste to avoid infections[17]. If a mistake occurs while segregating waste, it should not be corrected to prevent the contamination of the other waste [21]. MW should be stored safely to avoid unauthorized human contact, which can cause infections [17].

Separating Different Categories of Medical Waste

In medical centers, infectious and pathological waste, and sharps are placed in different containers. The containers are labeled as “biohazard”, closed, watertight and of uniform color for each type of MW throughout the medical center. The size of the containers depends on the volume of waste generated and the containers used are easy to handle and transport. For used needles specially designed containers are recommended.

The system for segregation, packaging, labeling, and marking involves separating the MW into categories, as described. The packaging is done in colored bags[22]. For example, yellow plastic bags are used for infectious MW that is meant to be disposed of by means of incineration or deep burial in landfill. However, if they are to be treated by autoclave or microwave, they are placed in red plastic bags or containers. In steam autoclaving, the waste is decontaminated by the effects of the saturated steam at elevated temperatures and high pressure. This method is not applicable for pathological, chemotherapy and radioactive waste.

Hazardous waste packaged in either blue or white transparent bags is usually treated by autoclave, microwave, chemical treatment, and shredding, or by landfilling. As for labeling and marking, W is known to have the bio-hazard symbol. Both the packaging and labeling are adopted worldwide[22].

Waste Collection and Transportation

The frequency of MW collection should be as high as once per day to avoid the accumulation of waste, which can spread infections. In addition, the personnel responsible for collection should be equipped with safety gear to prevent contaminations and infections [21]. The waste is collected from the health care entity and transported using secondary transportation to the treatment facility for disposal, recycling, and treatment processes. Treatment facilities are either located within the health care facility or off-site in a separate location [17].

Disinfection

In order to reduce the toxicity of some MW, chemical disinfectants (*i.e.* chlorine dioxide, sodium hypochlorite, or per acetic acid) are sometimes used. For solid waste, disinfection is effective if only waste materials are shredded. In some cases, the disinfectants themselves are

hazardous, thus it is not recommended for treating pharmaceutical, chemical and some types of infectious waste.

Waste Treatment

MW treatment is a process carried out before the disposal of MW to limit the hazardous effects of this type of waste on the environment and health. The lack of proper treatment can have several impacts, as follows [23]:

Poisoning from toxic elements,

Bacterial and fungal infections,

Release of toxins into the atmosphere,

Leaching to the soil and underlying aquifers,

Bioaccumulation,

Leaving a footprint on the environment,

Destruction of habitats.

In the production phase of any medical equipment, the impact of these types of equipment must be considered by performing a life cycle analysis and practicing proper treatment techniques. However, the methods and techniques for treatment have minimal impact in terms of carbon emissions released into the ambient air. For example, a

single intravitreal injection causes the release of 0.05 kg CO_2 during the disposal phase [24].

Incineration

Incineration is the most widely practiced treatment method due to its applicability to treating all waste types. The incineration process is carried out in furnaces operated at temperatures of 800–1200 C°. The high temperatures kill the pathogens, destroy 90% of organics, and change the waste characteristics such as weight, volume, and shape [25].

This process is governed by several parameters such as [26].

- Mixing of waste,

- Moisture content,

- Amount of waste in the furnace,

- Temperature,

- Residence time,

- Maintenance and repair.

Incineration produces fly ash and emissions such as dioxins, furans, and mercury. Dioxins and furans are considered carcinogenic, have a half-life ranging from 7 to 11 years, and are persistent footprints on the environment. Dioxin emissions can be reduced if the complete combustion of waste is achieved[25]. The dioxins emitted can also be treated using selective non-catalytic reduction. This technology depends on the production of free nitrogen via the reaction between nitric oxide and ammonia, and this gas is of high effectiveness and low cost[24]. Fly ash

is a solid residue from incineration, rich in heavy metals. Fly ash can be recycled but must undergo chemical pre-treatment first by using ethylene diamine tetra acetic acid disodium or sodium sulfide, which removes the heavy metals from the fly ash[25]. Approximately 3 kg of CO_2 is produced from burning 1 kg of clinical waste, therefore, incinerating MW contributes to global warming by releasing significant amounts of greenhouse gases, mainly CO_2 [27].

Autoclave Disinfection

Autoclave disinfection is a treatment method using temperature and steam simultaneously to kill microbes[17]. It is operated at a lower temperature than incineration but with pressure and steam influence to achieve disinfection[21]. The operating conditions are 60 min, at 121 C° and 1 bar, followed by a cycle of 60 min at 134 Cº to ensure the complete disinfection of waste [23]. The following aspects govern the operation of the autoclave [21]:

- Temperature (121–134 C°),

- Steam penetration,

- Waste load,

- Duration of the treatment cycle,

- Chamber air removal.

Due to the low operating temperatures of autoclaving, the waste appearance does not change, and the pathogens are not removed, which requires pre-treatment of the waste by incineration to be disposed of in landfills[17]. Thus, the autoclave is not optimum for all waste types.

Microwave Disinfection

Microwave disinfection uses low temperature and high microwaves for the reverse polymerisation and degradation of organic substances and microorganisms. The waves induce molecular bond vibrations, saving energy and preventing emissions, making it a more environmentally friendly method. The disinfection is operated at temperatures ranging between 177 and 540 Cº electromagnetic waves of wavelength ranging between 1 mm and 1 m and frequency ranges between 300 and 3000 MHz. Microwave disinfection has high costs and can be combined with incineration and autoclave [27]. The following aspects govern the operation of this method [23]:

- Waste characteristics,

- Moisture content,

- Microwave source strength,

- Exposure time,

- Degree of waste mixing.

Chemical Disinfection

Chemical disinfection is used to kill microorganisms and fight off pathogens by using chemicals . It is primarily used for treating liquid infectious waste such as blood, urine, feces, or hospital sewage. The chemical disinfectants that are commonly used are bleach solution

(1%) or a diluted active chlorine solution (0.5%). In addition, other disinfectants such as lime, ozone, ammonium salts, and peracetic acid can be used [21].

This treatment method directly affects those in charge of the treatment due to the inhalation of volatile chemicals or irritations to the skin and eyes [21]. The following aspects govern the effectiveness of this method [27]:

pH,

Contact time,

Waste and chemical mixing,

Recirculation versus flow.

The residues of this treatment are liquid and solid residues. The liquid residues are disposed of in the sewer system, and solid residues are disposed of in the landfill [28].

Waste Disposal

Rejects of the previous steps are transported to a sanitary landfill for disposal. However, landfills are not the optimum solution for handling MW due to their environmental effects. These effects are soil and water pollution caused by leachate and gas emissions into the air due to waste degradation [29]. Thus, the waste being disposed of should be minimized to the most, and achieving a circular economy guarantees that. Long-term decomposition of waste is the primary process responsible for waste disposal in landfilling[29]. Preventive measures should be taken to ensure the safe disposal of MW, which are [25]:

Rapid cover of waste,

Burying it under the old municipal waste of minimum burial of three months,

Waterproof bottom,

Minimum 2 m above the water

Emerging Technology

This method involves shredding and grinding the infectious medical waste bags via sharp cutting blades that are installed within the vessels. The blades rotate around 1750 revolutions per minute and the volume of the shredded waste is reduced by 80% [30]. The steps included in the process are loading, shredding, heating, sterilization, cooling, draining, vacuum and unloading. The whole process is enclosed in a compact system and there is no intermediate handling of the waste within the process. Due to its compact size, this system can easily be used for on-site treatment of waste and installed in hospitals. This will reduce the transportation costs of MW. In terms of environmental aspects, it is a clean and chemical-free technology and does not have any hazardous emission or radiation[30]. This method is economical and environmentally friendly and is reliable in terms of ease of use and maintenance. This technology is currently practiced in the middle eastern countries such as Iraq, Jordan, Kuwait, Lebanon, Syria, and UAE.

Similarly, a team of engineers in Idaho National Laboratory, USA have invented a new patented technology that helps in better management and treatment of MW. Based on this technology, Med-Shred, Inc., (Texas, USA) has developed a mobile shredding and chemical

disinfecting machine that is aimed for on-site treatment of hazardous MW[31]. The machine converts the MW into disposable municipal waste using shredders that shred the waste into smaller particles which are then wetted with disinfectant spray and immersed in a disinfection solution. The wet waste is then dried using a hot off-gas in a drying chamber. Considering the number of clinics and hospitals in middle east, this method will be very successful if utilized, as it can treat MW which helps in better management of waste.

Possible health risks of medical waste

It is difficult to measure the effects on the health of the population, bearing in mind that the concentrations of the effects of pollutants, which are present in the waste, predominantly small [32]. For most studies, waste management facilities are black boxes, which are supposed to emit toxic compounds, but without actual, quantified measurements that could be used in human health risk assessment[33]. Consequences caused by hazardous MW can be acute and chronic. After short-term exposure to dangerous substances, acute consequences occur, among which are burns caused by corrosive substances, eye irritation, inhalation of toxic gases. Chronic consequences occur after long-term exposure, and are difficult to predict, since they occur after several years, when their cause can hardly be determined[34]. Improper handling of MW represents a potential risk factor in the spread and transmission of infectious diseases. The risk group of transmission of infectious diseases includes primarily health workers, physicians and medical technicians, patients, staff employed in biomedical laboratories, logistics staff – hygiene services. This transmission is done through direct contact with the infected person and his body fluids, as well as indirectly through contaminated medical equipment. Precisely, percutaneous injuries are one of the most important risk factors for the transmission of

infectious diseases. Percutaneous injuries are divided into two types: injuries to the needles used in therapy and diagnosis and injuries to sharp objects (glass, scalpels). Centers for disease prevention and control from Atlanta in the United States indicate that about 1000 percutaneous injuries occur in hospital conditions daily[35]. The consequence of percutaneous injuries are microorganisms, i.e., causes of various infections in humans such as: infections caused by hemorrhagic fever viruses (e.g. Ebola), hepatitis B, hepatitis C, herpes, HIV, malaria, leprosy, typhus, syphilis, gonorrhea, diphtheria[36].

Conclusion

MW is highly hazardous and puts people at risk of fatal diseases. Understanding MW management and control techniques is important. In this paper, the definition of MW, MW management regulatory acts, the risks of exposure, MW management procedures and control techniques are presented. MW contributes to a considerable percentage of the total waste generated in most countries, and about 75% of MW is non-hazardous. The rest is hazardous since it is contaminated with infectious contaminants that can cause illness and transmit various diseases; therefore, proper handling and treatment of MW are needed. Better management can be implemented with appropriate (local) laws and regulations to reduce the risk of cross-contamination and decrease levels of emitted pollution from treatment and recycling of MW. In order to enhance MW management and treatment and make it more efficient and less damaging to the environment and to reduce the cost of production, disposal, and treatment, several aspects have to be considered: (i) to reduce the quantity of waste generated by regulating the use of materials and disposable equipment, (ii) to segregate the waste according to the regulations, with more strictness and attention, (iii) to limit the use of incineration, (iv) to follow stricter technological measures for the incineration of MW, e.g., filtration and

treatment of emissions from the incinerators, (v) to invest in new eco-friendly technologies for the disinfection and treatment of MW.

Conflict of Interest

The authors declare no conflict of interest.

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