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# A Review of Medical Waste Management Systems in the Republic of Korea for Hospital and Medical Waste Generated from the COVID-19 Pandemic

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**Abstract:** With the increasing generation of medical waste worldwide, managing medical waste has become crucial, given its potential environmental and public health risks. Previously in the Republic of Korea, medical waste was often mixed with municipal waste and disposed of in residential landfills or unsuitable treatment facilities (e.g., improperly managed incinerators). Environmental regulators and waste producers have made extensive efforts in recent years to improve waste management at healthcare facilities. This study presents an overview of the status of medical waste management in Korea and discusses information on the generation, composition, separation, transportation, and treatment of medical waste. Incineration was confirmed to be the most preferred treatment method for medical waste and was the only one used until late 2005. Large-scale medical waste incinerators are used for treating medical waste from most medical facilities in Korea; however, with increasing regulations on toxic air emissions (e.g., dioxins and furans), air emission standards are being tightened for all existing small-scale incineration facilities without air pollution control. Since medical waste usually contains various plastic materials such as polyvinyl chloride, these incinerators are highly likely to emit toxic air pollutants if improperly operated and managed. Waste minimization and recycling, control of toxic air emissions from medical waste incinerators, and alternative treatment methods to incineration are seen as major challenges. Incineration capacity cannot be expanded as quickly as the rising quantities of medical waste in Korea; thus, there is a growing need to reconsider the overall management system. Accordingly, we examined various medical waste treatment policies and methods that are being implemented in other countries, in addition to the main strategy of waste management. To determine preferable directions for the improvement of the medical waste management system, we investigated and compared the status of domestic and foreign waste management and proposed directions for improvement, focusing on several issues related to the current medical waste management system in Korea.

**Keywords:** medical waste; Republic of Korea; effective management; hospital/medical waste; COVID-19 pandemic



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## 1. Introduction

The quantity of medical waste in Korea generated by the medical industry has rapidly increased over the past decade. This medical waste is produced from the treatment, diagnosis, and vaccination of humans and animals in medical and veterinary facilities, health-related research centers, and medical laboratories. Though medical waste comprises only a small portion of all solid waste in Korea, it must be handled with care because it contains potentially infectious and hazardous substances [1]. Improper treatment of medical waste can seriously threaten human health and the environment. Problems caused by poor waste management include harm due to sharp tools, human diseases caused by infectious agents,

and environmental pollution from toxic and hazardous chemicals [2]; thus, medical waste management is a major concern for all regulators and demands continued attention [3–5].

In Korea, medical waste was regulated by the Medical Care Act of the Ministry of Health and Welfare until 2000. Medical waste was often mixed with municipal solid waste (MSW) and disposed of in municipal waste landfills or improper treatment facilities; moreover, information on handling and treating medical waste in medical institutions was highly limited and not widely known. Under the mounting challenge of medical waste management, Korea has continuously amended the Wastes Control Act to reinforce medical waste management from the point of generation to its final destination. Medical waste is classified as designated waste (or hazardous waste) and is subject to hazardous waste regulations under the Wastes Control Act. The Korean Ministry of Environment has disclosed several regulations on the definition, separation, packaging, tracking, and disposal of medical waste. According to the law, medical waste is defined as solid waste generated in medical and laboratory facilities operated by hospitals and is considered to be potentially harmful to health. Waste includes animal carcasses, human and animal parts, human and animal excrement, waste plastic material contaminated by blood, cultures, accumulations of infectious agents, waste medical equipment, and other waste containing infectious agents. Specifically, waste is classified into six major categories. It is noteworthy that the term "medical waste" has frequently been used interchangeably with other terms such as "hospital waste" and "infectious waste" worldwide (Table 1). Under a broader definition, hospital waste refers to any waste generated by hospitals, including infectious and non-infectious waste, hazardous waste and chemicals, and non-hazardous waste.

**Table 1.** Comparison of classification of medical waste.

| Category | Republic of Korea [1] | WHO [6] | USA [7] | EU [8] | Japan [9,10] | China [11] |
|---|---|---|---|---|---|---|
| Terminology | Medical Waste | Healthcare Waste | Medical Waste | Healthcare waste | Infectious Waste | Medical Waste |
| Sharps | Sharps | Sharps | Contaminated sharps/Unused sharps | Sharps | Infectious Industrial | Sharps |
| Body parts and organic including blood bags and blood preserves | Body parts and fluids/Blood contaminated/ Pathological test | Pathological | Bulk human blood/Pathological wastes | Body parts and organs including blood bags and blood preserves | Infectious Municipal | Human or animal pathological wastes, tissues, organs, blood, pus, body parts, and fluids |
| Waste whose collection and disposal is subject to special requirements to prevent infections | Infectious | Infectious | Isolation/Cultures and stocks of infectious agents and associated biologicals/animal wastes | Human and Animal Infectious | Infectious Industrial /Infectious Municipal | Infectious |
| Waste whose collection and disposal are not subject to special requirements to prevent infection (e.g., dressings, plaster casts, linen, disposable clothing, diapers contaminated with blood, etc.) | General | Infectious | - | Infectious | Infectious Municipal | Infectious |
| Chemicals consisting of or containing dangerous substances | Biological/ Chemical | Chemical | - | Chemical | | Chemical |
| Chemicals other than those mentioned in 18 01 06 | Biological/ Chemical | Chemical | Small volumes of chemical hazardous waste | Chemical/ Unused hazardous medicines | | Chemical |
| Cytotoxic and cytostatic medicines | | Cytotoxic | Antineoplastic drug | Unused hazardous medicines | | Chemical |
| Chemicals other than those mentioned in 18 01 08 | | Pharmaceutical | Small volumes of chemical hazardous waste | Unused non-hazardous medicines | | Medical |
| Amalgam waste from dental care | | Amalgam waste from dental care | - | Amalgam waste from dental care | | Amalgam waste from dental care |

Medical waste is often regarded as a subcategory of hospital waste, encompassing "potentially" infectious waste generated by medical facilities [12,13]. Globally, the terms "medical waste" and "healthcare waste" are used interchangeably. As shown in Table 1, "medical waste" in this study refers to all waste with an infectious potential generated during diagnosis, treatment, examination, and research in general hospitals, clinics, veterinary hospitals, and research institutes.

This study presents an overview and future directions of medical waste management in Korea and discusses the generation rate, treatment methods, and characteristics of medical waste. We discussed the basics of current waste treatment methods and the actual state of medical waste management. We also presented several proposals for improving medical waste management practices in Korea. Using national statistical data, we composed statistics on the amount of medical waste generated in hospitals and treated by type, as well as on the treatment methods used and the disposal of infectious medical waste [including medical waste produced during the ongoing COVID-19 pandemic. We then assessed the acquired data and presented an overview of the latest knowledge on medical waste management in Korea.

## 2. Materials and Methods

The research method included the collection of monitoring data on national medical waste generation and treatment, as reported by the Ministry of Environment, as well as site visits to medical waste treatment facilities, interviews, and conversations. We held meetings with field workers and experts from the government, industry, and academia. We then performed a literature review of published reports and scientific papers; and analyzed the available statistics and data on medical waste systems published by the Institute for European Environmental Policy (IEEP), Organization for Economic Cooperation and Development (OECD), and European Union (EU).

This study also examined the recent regulations on medical waste, as well as the published literature and media reports related to the recycling and disposal of medical waste. Medical waste classification systems and treatment methods were assessed based on statistics regarding the amount of medical waste generated, treated, and recycled in Korea by type from 2009 to 2017. We also used statistical data from the Ministry of Environment on the treatment methods and incineration throughput of COVID-19 infectious medical waste in Korea.

## 3. Results and Discussion

### *3.1. Definitions and Classification Systems of Medical Waste*

In Korea, "medical waste" is defined as "the waste specifically enumerated by the Presidential Decree among the waste discharged from public health and medical institutions, veterinary clinics, testing and inspection institutions, and other similar institutions, including such waste as the parts and extracts from human bodies and carcasses of laboratory animals, which may harm the human body through infection or otherwise and needs to be specially controlled for public health and environmental conservation." Medical waste in Korea is currently classified and managed as a designated waste. Medical waste is categorized into infectious, hazardous, and general medical waste, and hazardous medical waste is further divided into tissue, sharps, pathological test, biological and chemical, and blood-contaminated waste. Table S1 shows the degree of risk associated with medical waste, classified as infection, injury, intoxication, and ethical concerns. The degree of risk is shown for each of the current medical waste categories. Infectious medical waste and sharps waste are closely associated with infection, sharps waste is strongly associated with injury, biological and chemical waste with intoxication, and tissue waste with ethical concerns.

Medical waste-related terms and classification systems are consistently used worldwide. The US, Korea, and China make use of the term "medical waste"; the World Health Organization (WHO) and EU use "health-care waste"; and Japan uses the term "infectious waste" (Table S1). The "Safe Management of Wastes from Healthcare Activities" published

by the WHO in 2014 (hereinafter, "the WHO guidelines") defines all waste produced from medical practice and related research as "healthcare waste" [6]. The WHO guidelines classify healthcare waste into hazardous and non-hazardous healthcare waste. Hazardous healthcare waste is further classified into seven categories: sharps waste, infectious waste, pathological waste, pharmaceutical waste, cytotoxic waste, chemical waste, and radioactive waste (World Health Organization).

The EU uses the European Waste Catalogue (EWC), which consists of a six-digit code; the first two digits indicate the broad classification of the waste, the next two digits the sub-classification, and the last two digits the actual waste itself (Table 1). The EWC defines healthcare waste as waste generated during the treatment of humans and animals and during disease research, and Code 18 is assigned as the major classification. Healthcare waste classified under Code 18 in the EWC is divided into two sub-chapters: "wastes from natal care, diagnosis, treatment, or prevention of disease in humans" (18 01) and "wastes from research, diagnosis, treatment, or prevention of disease involving animals" (18 02). Each sub-chapter is further classified into the full EWC codes (9 items under 18 01 and 7 items under 18 02).

The EWC classifications comprise categories designated by six-digit codes; those presented in Table 1 are classified as "healthcare waste" (Table 1). Thus, "medical waste" in Korea is defined by the EU as "healthcare waste." Sharps are classified as 18 01 01/18 02 01; body parts and organs, including blood bags and blood preserves, as 18 01 02; waste whose collection and disposal are subject to special requirements to prevent infection as 18 01 03*/18 02 02*; waste whose collection and disposal are not subject to special requirements as 18 01 04/18 02 03; chemicals consisting of or containing dangerous substances as 18 01 06*/18 02 05; chemicals other than those mentioned in 18 01 06 as 18 01 07/18 02 06; cytotoxic and cytostatic medicines as 18 01 08*/18 02 07*; medicines other than those mentioned in 18 01 08 as 18 01 09/18 02 08; amalgam waste from dental care as 18 01 10; and metallic packaging containing a hazardous solid porous matrix (for example asbestos), including empty pressure containers, as 15 01 11 [8].

EU countries may reclassify healthcare waste according to the definitions of the European Working Council, even if they have a previously adopted definition and classification. For example, from 1992, Germany had previously classified medical waste into Group A (general household waste), B (waste contaminated with blood and body fluids), C + E (infectious waste and extracts), and D (chemicals), with a medical waste management system where Groups A and B were treated identically to household waste and Group C + E and D were treated according to type. Today, however, medical waste in Germany is classified with six-digit codes according to the EWC [14].

In the United Kingdom (UK), four commonwealths (England, Wales, Scotland and Northern Ireland) implemented the EWC in 2004 and 2005 to reform the medical waste management system. The UK uses a management system that largely follows the EU guidelines. The Controlled Waste Regulations (2012) of England and Wales classify clinical waste as waste from the healthcare and non-healthcare activities [15]. Waste from a healthcare activity includes waste that (i) contains viable microorganisms or their toxins, which are known or reliably believed to cause disease in humans or other living organisms; (ii) contains or is contaminated with a medicine that contains a biologically active pharmaceutical agent; or (iii) is a sharp object, body fluid, or other biological material contaminated with a dangerous substance according to the Council Directive 67/548/EEC. Waste from a non-healthcare activity of a similar nature to the above three descriptions is classified as clinical waste [16,17].

In Belgium, medical waste refers to "waste generated from the treatment and research of humans and animals," and is systematically managed up to the final treatment according to its risk-based classification, based on a view that emphasizes safe management over the issuing of penalties. In terms of risk, medical waste is divided into "high-risk medical waste (HRMW)" and "ordinary medical waste (OMW)," where HRMW is categorized into (i) infection risk; (ii) intoxication; (iii) sharps; (iv) ethical aspects—body organs, blood; and

(v) genetically modified organisms. Blood, as a liquid, is regarded as HRMW, and if HRMW and OMW are mixed, then the mixture is considered an HRMW.

The US Environmental Protection Agency (EPA) defines medical waste as "any solid waste that is generated in the diagnosis, treatment, or immunization of human beings or animals, in research pertaining thereto, or in the production or testing of biologicals" (Table 1). Medical waste is categorized as an industrial waste classified as non-hazardous waste but is managed separately from other industrial waste (Table 1). To comprehensively manage the generation, movement, and treatment of medical waste and ensure that the improper disposal of waste does not cause harm to humans and the environment, the US EPA amended the Resource Conservation and Recovery Act and implemented the Medical Waste Tracking Act from November 1988 to June 1991. Through this, a tracking system was established for the discharge, collection, transportation, and treatment of medical waste; the tracking system compiled opinions on its effectiveness, potential threats posed by medical waste, types and generated amounts of medical waste, and national legislation. The medical waste tracking method was applied to infection-related culture media or strains, pathological waste, blood, sharp instruments, contaminated laboratory animal waste, and isolated medical waste from infectious disease patients [7]. Since then, the US EPA has recommended that each state develop a waste management system based on the Medical Waste Tracking Act and provide model storage, transportation, and treatment guidelines for medical waste management [18]. In practice, however, even the term for "medical waste" varies among the states, and is indicated with terminologies such as "regulated medical waste" (New York, Rhode Island, Virginia, etc.), "infectious waste" (Colorado, New England, Nevada, etc.), "biomedical waste" (Connecticut, Florida, Georgia, Maine, Washington, etc.), and "special medical waste" (Maryland, etc.); there are also differences in the regulations being implemented at various levels [19].

In Japan, waste is classified into industrial waste and municipal waste, and waste under each category requiring special treatment is managed as "specially controlled waste" as shown in Table 1. Concerning medical waste, infectious or potentially infectious waste is classified as specially controlled waste, which is further divided into "specially controlled industrial waste" or "specially controlled municipal solid waste" according to type (Ministry of Environment Japan). Infectious MSW is defined as being infectious because of materials from medical institutions such as tissues, bandages, and sanitary cotton, while infectious industrial waste is defined as being infectious because of the presence of blood (waste alkali or sludge), needles (metal waste), and X-ray fixative (spent acid) [20].

Table 2 shows a comparison of medical waste by country and type. It is classified into infectious medical waste, tissue waste, pathological waste, injury waste, biological and chemical waste, blood-contaminated waste, and general medical waste. As demonstrated, the scope and classification systems vary for each type of general medical waste. For example, in Korea, Germany, and the UK, waste is defined as "waste whose collection and disposal is not subject to special requirements to prevent infection (e.g., dressings, plaster casts, linen, disposable clothing, diapers contaminated with blood, etc.)." Waste classified under 18 01 04/18 02 03 is defined as general medical waste in the WHO guidelines but does not fall into the category of medical waste that must be specially controlled in the US, Japan, and China.

### *3.2. Comparison of Collection, Storage, Transport, and Treatment of Medical Waste*

Table 3 shows the characteristics of medical waste management systems in Germany, Belgium (Flanders), the US, Japan, Korea, and China. Overall, medical waste-related regulations are the strongest in Korea, followed by Belgium (Flanders), Germany, Japan, the US, and China.

**Table 2.** Comparison of medical waste type in each country.

| | ROK | USA | Germany | UK | Japan | China |
|---|---|---|---|---|---|---|
| Infectious medical waste | All waste from medical practices for persons isolated to protect others from the infectious diseases specified under Article 2-1 of the Infectious Disease Control and Prevention Act | Isolated waste/infectious pathogens and related organism media | Wastes whose collection and disposal is subject to special requirements to prevent infection | Infectious waste/contaminated infectious clinical waste | Place of discharge: Material discharged after being used for treatment, examination, etc. in infectious disease beds, tuberculosis beds, operating rooms, emergency outpatient rooms, intensive care units, and examination rooms<br>Types of infectious diseases: Class I, II, III, IV, and V Infectious Diseases, Novel Influenza Infection, etc., Designated Infectious Disease, New Infectious Disease, Tuberculosis Examination, etc. under the Act on the Prevention of Infectious Diseases and Medical Care for Patients with Infectious Diseases | Material that is carrying a variety of pathogenic microorganisms and spreading the risk of infectious disease induced (blood, blood products, and objects that are polluted with them; quarantine waste; microbiology laboratory waste; dialysis waste; used surgical operation clothes; infectious organ pieces, blood and anything contaminated with these materials) |
| Tissue waste | Human or animal tissues, organs, body parts, animal cadavers, blood, pus, and blood products (serum, plasma, blood derivatives) | Animal waste | Body parts and organs, including blood bags and blood products | - | Form: Pathological wastes (organs, tissue, skin, etc.) from surgery, etc. | Human or animal pathological waste, including tissues, organs, blood, pus, and body parts and fluids |
| Pathological waste | Culture media used for testing/examination, culture vessels, stored strains, waste test tubes, slides, cover glass, waste media, waste gloves | Pathological waste | - | - | Form: Material used for tests, examinations, etc. related to pathogenic microorganisms (media, laboratory animal cadavers, test tubes, Petri dishes) | Human body waste and medical experimental animal carcasses produced during processes of diagnosis and treatment |

**Table 2.** *Cont.*

| | ROK | USA | Germany | UK | Japan | China |
|---|---|---|---|---|---|---|
| Injury waste | Injection needles, suture needles, surgical blades, acupuncture needles, dental needles, broken glass of testers | Injury waste/unused injury waste | Pointed or sharp objects | Non-contaminated injury waste | Form: Sharp objects stained with blood (including broken glass fragments, etc.) | Medical sharp waste that can hurt or cut the human body (needles, syringes, broken glass, blades, and other items that could cause a cut or puncture) |
| Biological and chemical waste | Lung vaccines, lung cancer drugs, lung chemotherapy drugs | Anticancer drugs/small amounts of chemically harmful substances | Chemicals/cytotoxic drugs and mitogens consisting of or containing dangerous toxic substances | Cytotoxic and cytostatic waste | - | Medicine waste: Medicine waste of expired, obsolete, deteriorated, or contaminated (common medicines that are expired or are no longer required or are discarded; other medicines discarded that could cause cancers or genetic diseases; the discarded vaccine products) Chemical waste: toxic, corrosive, flammable, and explosive chemical goods (hazardous chemicals; heavy metal-containing waste; pharmaceutical waste; amalgam wastes; gynotoxic waste; genotoxic waste |
| Blood-contaminated waste | Waste blood bags, waste used in hemodialysis, and other waste requiring special control because they contain enough blood to leak | Blood | - | - | Form: Blood, etc. (blood, serum, plasma, and body fluid) | - |

**Table 2.** *Cont.*

| | ROK | USA | Germany | UK | Japan | China |
|---|---|---|---|---|---|---|
| General medical waste | Sanitary cotton, bandages, gauze, disposable diapers, sanitary napkins, disposable syringes, and infusion sets containing blood, body fluids, secretions, and excrement | - | Wastes whose collection and disposal is not subject to special requirements to prevent infection/amalgam waste from dental care | Sanitary/diaper waste, etc. | - | - |
| Other medical waste | - | Low-concentration radioactive waste | | Pharmaceutical waste | If there are no applicable items from Step 1 to Step 3, it is classified as non-infectious waste * | |
| Remarks | Wastes Control Act Enforcement Decree (see Supplementary Material) Types of Medical Waste | US EPA (https://www.epa.gov/sites/default/files/2016-02/documents/model_guidelines_for_state_medical_waste_management.pdf (accessed on 31 May 2021)) | EU Waste Framework Directive 2008/98/EC | UK, Waste control regulations (England and Wales regulations 2012;2012;811) | Japan Ministry of the Environment, Infectious Waste Disposal Manual | Healthcare Waste Management regulation |

* According to the protocol for determining infectious waste in Japan, waste is classified as infectious waste or non-infectious waste through Step 1 (Form), Step 2 (Place of Discharge), and Step 3 (Type of Infectious Disease).

**Table 3.** Comparison of medical waste management methods.

| Country | Discharge/Container | Storage | Transport | Disposal |
| --- | --- | --- | --- | --- |
| USA | • Individual laws and regulations in each state<br>• Dedicated containers and sealed discharge from the generation stage<br>• Hazard label on the outer packaging<br>• Barcodes attached in medical institutions where possible | • Individual laws and regulations in each state<br>• In Mississippi, it is prohibited to store infectious waste at 6 °C or higher for 7 days, and if stored at 0 °C or lower, it may be stored for 90 days without obtaining special permission | • Federal laws related to the US Department of Transportation and individual regulations under state laws<br>• Prevention of damage to waste containers<br>• Sterilization of transport vehicles<br>• When transporting off-site from hospital facility, load in a sturdy container and use leak-proof truck<br>• about 500 km | • Final treatment methods such as steam sterilization, incineration, chemical sterilization, thermal inactivation, and sanitary landfill after intermediate grinding are suggested according to the type of medical waste |
| Japan | • Dedicated containers and sealed discharge from the generation stage<br>• Collection containers for each type of medical waste; color regulations<br>• Some hospitals use a tracking management system using IC tags | • Short-term storage in principle; refrigeration for long-term storage of potentially perishable waste | • Must use cover, lid, and roof; for transport vehicles without a cover, the packaging container must not be affected by rainwater<br>• about 100 km; 2 h | • Infectious potential is eliminated from infectious waste via incineration, etc. before the final treatment<br>• Treatment by incineration, dissolution, high-pressure steam sterilization, dry heat sterilization, etc. |
| Germany | • Container type and material according to the type of medical waste are presented in the Supplementary Material: Table S2<br>• Regulations on separating hazardous waste from other wastes | • Infectious waste:<br>Stored at temperatures of −15 °C or below (can be stored for up to one week)·<br>• At 8 °C or below, the storage period can be extended after consultation with a hospital hygiene expert<br>• Body organs/blood, etc.:<br>• Can be stored for up to 6 months while frozen or under the same conditions as infectious waste<br>• Store in ventilated storage | • There are regulations on pressure difference rather than temperature: practically kept at 0 °C<br>• about 100 km; <2 h | • Maximize recycling; landfilled as the final treatment<br>• Infectious waste treated at special waste incineration facilities<br>• Non-infectious medical waste may be incinerated at general incineration facilities after sterilization (93 °C for 10 min) via a method certified by the Robert-Koch Institute |

**Table 3.** *Cont.*

| Country | Discharge/Container | Storage | Transport | Disposal |
| --- | --- | --- | --- | --- |
| UK | • Collection containers for each type of medical waste; color regulations | | Follows ADR regulations | • Contaminated waste is incinerated<br>• Recycling and sanitary landfill after intermediate treatment are suggested for final treatment according to the type of medical waste |
| Republic of Korea | • Dedicated containers and sealed discharge from the generation stage<br>• Regulations on storage period, storage conditions, images, and color according to the type of medical waste<br>• Inspection standards provided for dedicated containers<br>• RFID implemented for medical waste monitoring and handover system | • Infectious medical waste and tissue waste stored at 4 °C<br>• Must be kept at 4 °C or less if stored by a collection/transport company in a temporary storage site. Storage period limited to 5 days in dedicated storage facilities and 2 days in other facilities<br>• For medical waste stored by an intermediate disposal company, daily storage must not exceed 5 days of the disposal capacity, and the storage period is limited to 5 days | • Installation and operation of refrigeration facilities at 4 °C or below for collection and transport vehicles; installation of sealed cargo boxes<br>• Regulations on storage facilities and chemicals needed to disinfect the inside of carbo boxes<br>• about 350 km; about 4 h<br>• Body of the collection and transport vehicle is white, with the image of the medical waste, business name, and phone number written on both sides of the cargo box and image of medical waste indicated on back; the text color is green | • Medical wastes other than recycled placenta are disposed of at incineration facilities or sterilization/grinding facilities (on-site/outsourced treatment)<br>• For medical waste stored by an intermediate waste disposal company, daily storage must not exceed 5 days of the disposal capacity, and the storage period is limited to 5 days<br>• Residues after incineration are landfilled |
| China | • Using colored bags and containers (plastic, metal, or paper)<br>• Of the hospitals, 73% use a segregated collection for all medical waste, while 27% of the hospitals have not yet implemented segregated collection for all medical waste<br>• Infectious waste (yellow bags); municipal waste (black bags); sharps (plastic containers; cytotoxic/cytostatic drugs (original packaging) | • Medical institution can install temporary storage facilities (2 days)<br>• Cannot store medical waste in the open air.<br>• Storage conditions of low temperature and anti-corrosion<br>• Responsible for collection and transport at medical storage institutions and storage and disposal of medical waste | • The disposal companies arrange for special trucks to collect medical waste from various hospitals once every 1–2 days. | • Incineration technology (rotary kiln, pyrolysis, etc.) is considerably advanced and suitable for treating medical waste, and operators are experienced in installation and operation. Therefore, it has been the preferred option.<br>• Due to lack of experience in large facilities of high-temperature evaporation technology (pyrolysis), technical standards applicable to small facilities were enacted and pilot facilities were installed and operated |

3.2.1. Collection and Storage at Discharge Facilities

In Korea, institutions that discharge medical waste must establish a separate location for transporting and storing the waste off-site until it is treated and must disinfect it at least once a week. Highly infectious medical waste and tissue waste, including placental tissue, must be stored at 4 °C or below in a dedicated plastic container. Sharps waste must also be stored in a dedicated plastic container (Table 3). The storage period for infectious medical waste is 7 days, while sharps waste can be stored for up to 30 days. Other types of solid medical waste are collected using plastic bags and dedicated cardboard containers.

In Germany, the storage period for infectious waste at temperatures of 15 °C or below must not exceed one week, while it can be extended after consultation with a hospital hygiene expert at temperatures of 8 °C or below [21]. The same temperature conditions apply to body parts, organs, and non-infectious blood products, though they can be stored for up to 6 months in a deep-frozen state. In Flanders, Belgium, HRMW is collected in three types of containers: plastic sanitary boxes, boxes with a plastic bag, and needle collection containers. HRMW is placed in a separate locked container, while OMW is compressed using a container press and moved to the storage site. The warehouse where HRMW is stored is maintained below 7 °C and kept clean [22,23].

In the US, medical waste is separated at the point of generation and stored in an appropriate container [7]. For example, containers used for sharps waste include heat-resistant containers, plastic containers for solids that cannot be reopened once the lid is closed, and translucent containers to show how many needles and similar materials are in the container [7]. Medical waste is packaged in two layers and labeled on both sides; the outer packaging (e.g., box) is made of a hard material to prevent damage during loading, collection, transportation, etc. The inner packaging must not be reused, and must be tightly tied to prevent waste liquid from leaking. If the medical waste is not immediately treated, a suitable storage site must be secured and kept clean. Though the specific temperatures and storage periods are not provided, minimizing the storage time is suggested. In Japan, infectious waste is tracked and recorded from generation to the final treatment using a dedicated container, although the storage temperature at the discharge facility is unregulated [9]. Waste in China is collected in colored bags and containers (made of plastic, metal, and paper) for the following: infectious waste (yellow bags), municipal waste (black bags), sharps (plastic containers), and cytotoxic/cytostatic drugs (original packaging) [24].

3.2.2. Transportation and Outsourced Incineration

Table 3 compares the transport methods and conditions for medical waste in each country. In Korea, only incineration is permitted as an outsourced treatment method; however, there are only about 15 medical waste-dedicated, outsourced incinerators nationwide, and hence, the transportation distance is longer than that in other countries. Medical waste is generated mainly in Seoul and Gyeonggi Province, but these are mostly transported to the Gyeongsang Province for treatment, as the incineration capacity is concentrated there. As a result, medical waste is transported up to approximately 350 km by dedicated vehicles with containers maintained at 4 °C or below.

In Germany, infectious waste and highly toxic chemicals are transported to hazardous waste incinerators with transport distances of approximately 100 km. There is no regulation stipulating that the transport vehicles must transport only medical waste, and temperature is unregulated during transportation, although in practice, it is transported at low temperatures such as 0 °C, depending on the transport company. There are also regulations for ensuring that the dedicated containers withstand pressure from the gas generated inside them. In Belgium, incineration is seen as the safest treatment method; thus, all non-recyclable waste is treated using incineration. There are separate incinerators specifically for medical waste, but there is no regulation, such as that in Korea, stipulating that they can incinerate only medical waste. Transportation distances are short due to the small land area. There is no regulation on temperature during transportation and none

stipulating that only medical waste can be transported. In the US, medical waste is sometimes transported at long distances up to 500 km, but this has limited significance because there is no extensive dependence on outsourced incineration. There are no regulations on temperature during transportation or dedicated vehicles for transporting medical waste.

Japan has no regulations on temperature or dedicated vehicles for transporting medical waste as well, and transport distances range up to approximately 100 km, similar to Germany. Overall, the dependence on outsourced incineration is moderate and is growing, although Japan does not designate dedicated incinerators for treating medical waste, as does Korea.

#### 3.2.3. Treatment Methods at the Discharge Facility

Table 3 compares the treatment methods for medical waste in each country. In Korea, it is permitted to sterilize and grind medical waste using ultrasonic waves or steam on-site, though only one hospital in the country is operating a sterilization grinder using ultrasonic waves. In Belgium, autoclaving is the only recognized on-site treatment. Owing to the country's small size and area, all waste treatment is centered on incineration and the proportion of on-site treatment is very low, with no cases of residues being landfilled. In Germany, sterilization according to stipulated conditions using steam or ultrasonic waves is permitted as an on-site treatment method, and the residues after treatment can be landfilled. In the US, methods using steam or ultrasonic waves and chemical treatment are generally suggested, after which the treated products can be landfilled [7,18]. As the scope of medical waste management expands in the US, on-site treatment methods are expected to become more active. In Japan, the permitted on-site treatment methods include melting and steam and dry heat sterilization. The treated products can also be landfilled, but the proportion of landfilled medical waste is gradually decreasing [9].

#### 3.2.4. Treatment of General Medical Waste

In Korea, general medical waste classified under EWC code 18 01 04/18 02 03 is collected using dedicated containers, following which most of it is incinerated in dedicated medical waste incinerators and then sent for further outsourced incineration (Table S2). It is important to note that, in Korea, diapers used to be classified as medical waste, but were re-classified as municipal waste in 2020.

In the US and Germany, this type of medical waste is generally treated in the same manner as municipal waste; however, in Germany, certain hospitals treat blood-stained medical waste in the same manner as infectious waste.

In Belgium, blood-stained medical waste is treated as HRMW and other waste is treated the same as municipal waste, while in Japan, blood-stained gauze and diapers are treated as infectious municipal waste [22]; in addition, in Japan, diapers that do not contain blood are treated as non-infectious municipal waste, and therefore, in contrast to the current management system in Korea, other countries regard general medical waste as not highly infectious, and in some cases, the possibility of infection is recognized, but is limited to only certain situations.

### *3.3. The Korean Medical Waste Management System*

#### 3.3.1. Status of Medical Waste in Korea

Generation and Treatment of Medical Waste in Korea

Figure 1 shows the trend of medical waste generation in Korea based on statistical data. Medical waste generation steadily increased from 115,054 tons/year to 238,272 tons/year from 2010 to 2018. In 2018, it increased by 52% compared to 2010 and 16% compared to 2015. Medical waste is categorized into general medical waste, hazardous medical waste, and infectious medical waste, which increased in amount by 47%, 63%, and 94% in 2018 compared to 2010 (Figure 2a). In 2018, the amount of medical waste generated by type was as follows: 173,922 tons/year (general medical waste), 60,379 tons/year (hazardous medical waste), and 3972 tons/year (infectious medical waste). Medical waste generation

is continuously growing worldwide, with both developed and developing countries are showing steady increases [25]. We investigated the generation of general medical waste, which was divided into six categories: "Placenta medical waste," "Bio&Chemical medical waste," "Damaging medical waste," "Tissue medical waste," "Pathology medical waste," and "Blood medical waste." The changes in generation in 2018 compared to 2015 were as follows: "Bio&Chemical medical waste" showed 51% increase; "Tissue medical waste," 44% increase, "Placenta medical waste," 37% increase; "Damaging medical waste," 27% increase; "Pathology medical waste," 11% increase; and "Blood medical waste," 2% decrease (the only category that showed a decline) (Figure 2b).

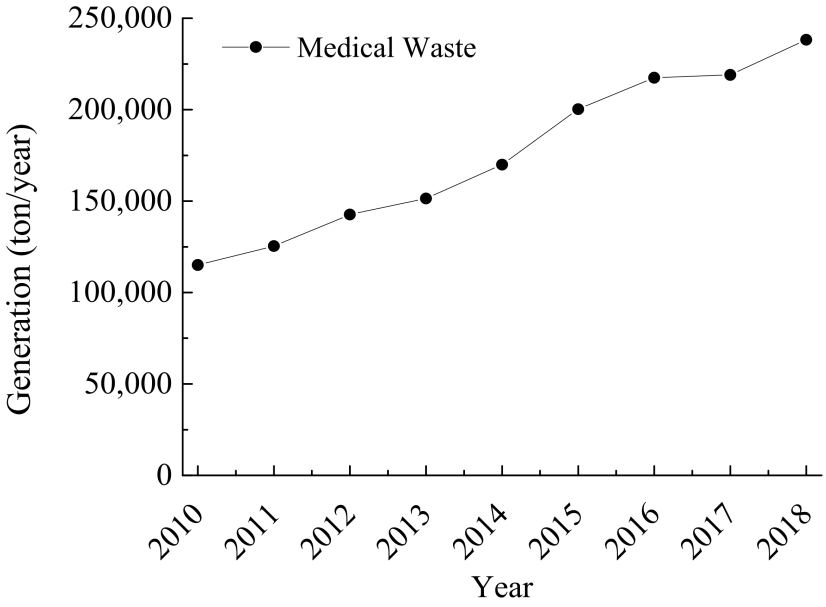


**Figure 1.** Generation of medical waste in the Republic of Korea from 2010 to 2018.

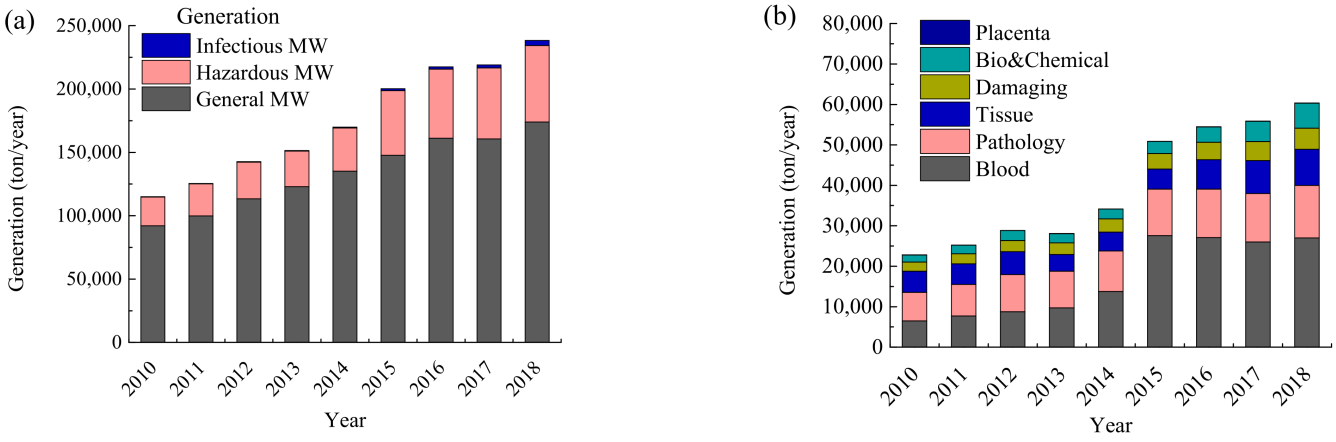


**Figure 2.** Generation of (**a**) different types of medical waste and (**b**) general medical waste in the Republic of Korea. MW—medical waste.

Figure 3a shows the trend of the amount of medical waste treated in Korea over eight years. The amount of treated medical waste steadily increased from 115,396 tons/year to 238,7899 tons/year from 2010 to 2018. In 2018, it increased by 52% compared to 2010 and 16% compared to 2015. Treatment of general medical waste, hazardous medical waste, and infectious medical waste increased by 47%, 63%, and 94%, respectively, in 2018 compared to 2010 (Figure 3a).

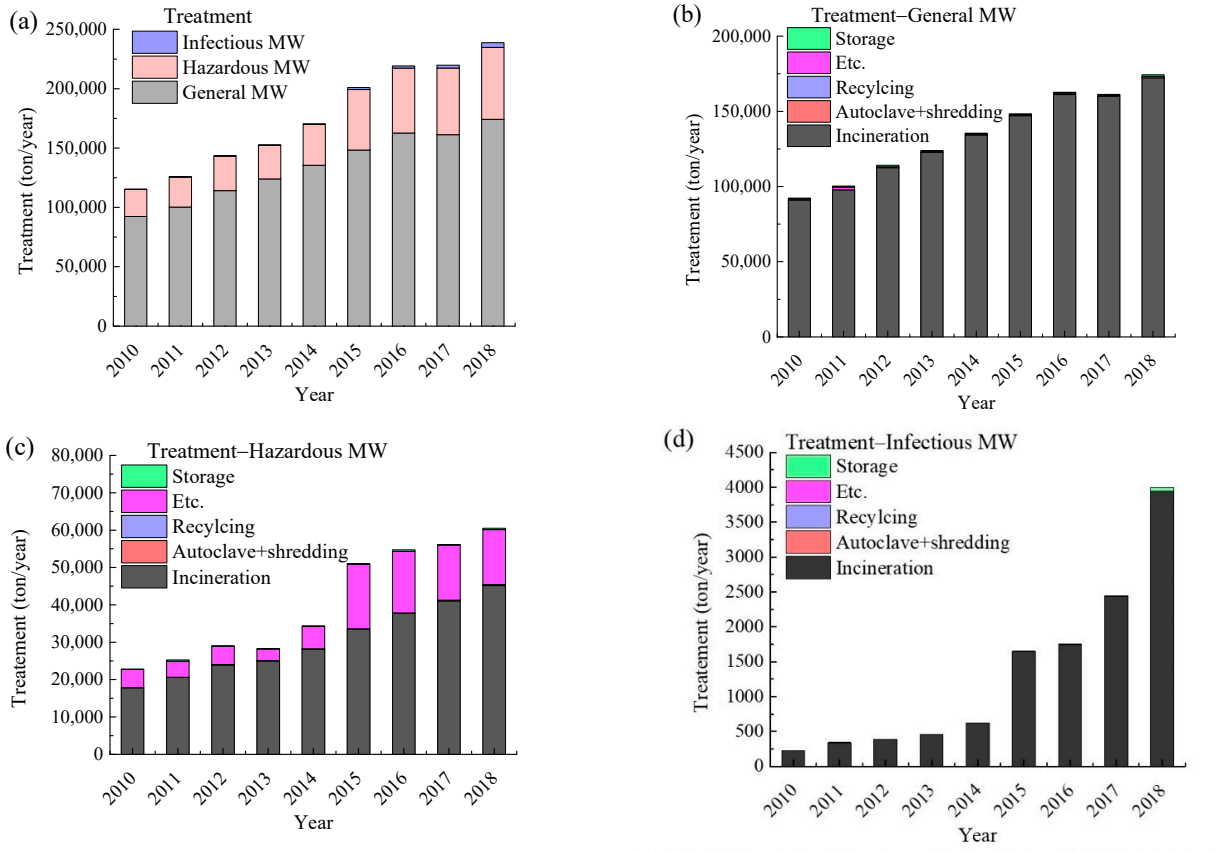


**Figure 3.** Treatment of (**a**) medical waste, (**b**) general medical waste, (**c**) hazardous medical waste, and (**d**) infectious medical waste in the Republic of Korea from 2014 to 2018. MW, medical waste.

In 2018, the amount of medical waste treated by type was as follows: 174,278 tons/year (general medical waste), 60,518 tons/year (hazardous medical waste), and 3993 tons/year (infectious medical waste). Treatment of general medical waste can be divided into six categories, namely, "Storage," "Miscellaneous," "Recycling," "Autoclave + shredding," and "Incineration." Of the total general medical waste, more than 99% is incinerated (Figure 3b). For hazardous medical waste, 78% or more is incinerated, while 14% to 76% is treated by methods under listed under the category "Miscellaneous" and 1% is treated by "Autoclave + shredding" (Figure 3c). The data for the treatment methods listed under "Miscellaneous" refer to the following: (other treatment amount + final stored amount) − amount carried over from the previous year. "Other treatment amount" refers to the concentrate (blood and liquid waste) generated from sterilization, grinding, and wastewater treatment facilities. Hazardous medical waste has rapidly increased since 2015 and is mostly treated via incineration in Korea, unlike the combined use of various methods of medical waste treatment in other countries. After categorizing infectious medical waste by treatment, we found that more than 99% was treated via incineration (Figure 3d). The amount of infectious medical waste that was subjected to incineration increased by 63% in 2015 compared to 2010, 62% in 2014 compared to 2015 (Ebola virus), and 58% in 2018 compared to 2015 (Middle East Respiratory Syndrome, MERS).

### Medical Waste Treatment Methods and Status in Korea and Other Countries

Medical waste treatment in Korea is divided into two categories: chemical treatment and thermal treatment. Medical waste is subjected to chemical treatment, steam sterilization, and microwave treatment. Chemical treatment methods account for approximately 10% of the total medical waste treatment carried out in Korea; these methods mainly involve sterilization using peracetic acid and can treat waste in a short time, about 25% faster than

the treatment methods used in Japan. Steam sterilization, the most common treatment method used worldwide, accounts for 45% of the medical waste treatment carried out in Korea. It involves treating waste for 30 min at 121 °C or higher before treating it with steam (100 °C) for 40 min at a temperature of 165 °C or higher. The US and China require at least a 4-log reduction (99.99%) for sterilization. In Korea, microwave sterilization accounts for 45% of all medical waste treatment (Table 4).

The installation standards for sterilization and grinding facilities in Korea currently stipulate only three thermal treatment methods: steam, thermal tube, and microwave. Since chemical treatment and other methods (such as radiation or equivalent conditions) are not included, the diversification of intermediate treatment is inadequate. In contrast, international guidelines (the Basel Convention, WHO, the US, Japan, and the UK) allow various legal standards for the intermediate treatment of medical waste, including chemical treatment.

Table 5 summarizes the current status of regulations on treating and reinforcing the management of COVID-19 infectious waste in Korea. In Korea, the Ministry of Environment treats waste related to COVID-19 as medical waste. Infectious medical waste is immediately placed into dedicated containers at the place of discharge (to minimize movement within the hospital), sealed (double-sealed with a dedicated bag and container), and then discharged. Disinfection is performed before and after placing the waste in the container. Food leftovers from COVID-19 patients are also placed into infectious medical waste containers and then treated. The waste is taken out on the same day to minimize storage in the hospital, and when stored, it is stored separately from other waste in a designated warehouse. The containers are directly sent to a medical waste incineration company without passing through temporary storage and are immediately incinerated upon receipt.

In addition, in Korea, all waste produced by confirmed patients at residential treatment centers (including food waste) must be treated as infectious medical waste, which requires disinfection, sealed discharge, regular disinfection, and daily incineration. During discharge, the patient directly disinfects the waste, seals it in a dedicated bag and synthetic resin container, and leaves it in front of the door. This must be collected and disinfected by the management personnel at a designated time daily and stored in a separate designated (temporary) storage site. The designated collection and transport company transports the waste from the (temporary) storage site to the designated treatment company on the same day, after which the waste is incinerated. The separate (temporary) storage site must be disinfected once a day. Municipal waste produced during the operation and support of residential treatment centers without contact with confirmed patients should be incinerated similar to general medical waste. Self-quarantine patients disinfect their waste (including food waste), seal it in a dedicated medical waste bag, put this bag into a standard garbage bag, and contact the health center to discharge the waste. The City Department(s) of Municipal Waste collect and incinerate this as municipal waste. Waste produced at quarantine locations, where suspected or confirmed cases of COVID-19 are isolated, is disinfected, sealed in a dedicated medical waste bag, and stored in a double-layer standard garbage bag. In principle, the medical waste collection, transport, and treatment company contracted by the health center collects this in a synthetic resin container and incinerates it on the same day. For disposing of waste in places visited by confirmed patients and multiuse facilities, the areas exposed to COVID-19 patients are properly disinfected according to the Korea Disease Control and Prevention Agency guidelines, after which access to these areas is prohibited until the next day. The waste is placed in a standard garbage bag, double-sealed, disinfected, and then incinerated at a public incinerator. Cleanroom garments and masks used during disinfection are treated as medical waste. To further prevent the spread of infection, the waste generated after disinfection in group and multiuse facilities is also double-sealed, disinfected, and then incinerated at a public incinerator.

**Table 4.** Disposal technologies of medical waste in different countries.

| Disposal Technology | | WHO | Basel Convention | USA | | Japan | China | Republic of Korea |
|---|---|---|---|---|---|---|---|---|
| | | | | California | Florida | | | |
| Physical disposal | Shredding Grinding Mixing | • Mostly not used alone; complementary treatment combined with other treatment technologies | | | | | | |
| Chemical disposal | Disinfectant disposal | • Oxidation treatment ($ClO_2$, NaOCl, $C_2H_4O_3$, limewater, ozone gas, calcium oxide, etc.) | • Waste exposed to chemicals with sterilizing action | • Approved by the department | • Treated with sodium chlorite, glutaraldehyde, and quaternary ammonium<br>• Biological indicator: *Bacillus subtilis*<br>• At least a 4-log reduction (99.99%) is required for sterilization, but temperature and time conditions are not specified | • Treated with hypochlorous acid (1000 ppm, at least 60 min)<br>• Treated with glutaraldehyde (2%, at least 60 min) | • Chlorinated disinfectant with a concentration of 1000 mg/L lime powder (purity 88~95%, 120 min; lime powder/medical waste = 0.075 kg/kg; pH 11–12.5), sodium hypochlorite, calcium hypochlorite, chlorine dioxide etc.<br>• Biological indicator: *Bacillus subtilis* black spores<br>• Killing log value shall be not less than 4 | • Treated with peracetic acid (2%) at 40 °C for at least 15 min |
| | Alkali hydrolysis | • Tissue decomposition, infectious waste, dissection waste<br>• Applied to roadkill cadavers, etc. | | | | | | |
| Biological disposal | Composting Earthworm farming | • Applied to hospital food, organ extracts, placenta extracts, etc. | | | | | | |

**Table 4.** *Cont.*

| Disposal Technology | | WHO | Basel Convention | USA | | Japan | China | Republic of Korea |
|---|---|---|---|---|---|---|---|---|
| | | | | California | Florida | | | |
| Thermal disposal | Steam sterilization (steam disposal) | • Steam used to sterilize waste<br>• Autoclave can be used for a wide range of waste<br>• To suppress aerosol generation, air must be removed beforehand and a HEPA filter must be used | • Waste exposed to saturated steam under pressure in a pressurized container or autoclave | • 121 °C (250 °F), at least 30 min (treatment conditions subject to change)<br>• Biological indicator: *Geobacillus stearothermophilus* | • Biological indicator: *Bacillus stearothermophilus*<br>• At least 4-log reduction (99.99%) for sterilization | • At least 20 min in moist heat at 121 °C or higher | • 134 °C, 220 kPa, 45 min, 0.3 0.6 MPa<br>• after autoclave steaming, the water content of medical waste shall not exceed 20%<br>• Diameter of the medical waste particles after crushing shall be maintained less than 5 cm.<br>• Biological indicator: *Bacillus subtilis* black spores<br>• killing log value shall be not less than 4 | • Keep at 121 °C or higher under atmospheric pressure of 1 atm or higher for at least 30 min<br>• Moisture penetration via steam at 100 °C, then heat at the rotation speed of at least 4 times per minute and high temperature of 165 ± 5 °C in a spiral heat tube, and keep in sterilization room for at least 40 min at 100 °C or higher |
| | | | | • 104 to 115 °C, no more than 60 min<br>• Treatment within 30 min<br>• Treatment with steam and $CO_2$<br>• Physically encapsulated after sterilization at high temperature | | | | |
| | Dry heat sterilization | • Heated via conduction or convection using infrared or heater without moisture or steam | • Waste exposed to heat at specified temperature for a sufficient period | | • Biological indicator: *Bacillus subtilis*<br>• At least 4-log reduction (99.99%) is required for sterilization, but temperature and time conditions are not specified | • 180 °C at 30 min or more | • 300 Pa, Temperature: 180~200 °C, 20 min<br>• Stirring device: no less than 30 r/min | |
| | Microwave | • Water heating sterilization using microwave energy | | | • *Bacillus subtilis* used as indicator microorganism<br>• At least 4-log reduction (99.99%) for sterilization<br>• 95~100 °C, 30 min | | • (915 ± 25) MHz or (2450 ± 50) MHz<br>• Not less than 95 °C, 45 min<br>• Diameter of the medical waste particles after crushing shall be maintained less than 5 cm.<br>• Biological indicator: *Bacillus subtilis* black spores<br>• Killing log value shall be not less than 4 | • Moisture penetration with 160 °C high-temperature steam, then keep for at least 25 min at 95 °C or more under 4 or more microwave generators, each with a frequency of 2450 MHz and output of 1200 W |

**Table 4.** *Cont.*

| Disposal Technology | | WHO | Basel Convention | USA | | Japan | China | Republic of Korea |
|---|---|---|---|---|---|---|---|---|
| | | | | California | Florida | | | |
| Radiation (irradiation) disposal | Cobalt 60 | • Electron beam irradiation using cobalt 60 or ultraviolet source | • Numerous restrictions and considerations regarding its use | | | | | |
| | UV-rays | • Used to sterilize airborne microorganisms | | | | | ✗ | |
| Other disposals | | | • Numerous restrictions and considerations regarding the use of microwaves and encapsulation | | | | • Reverberatory incineration (850 °C), microwave disinfection, pyrolysis incineration, rotary kiln incineration | |
| Reference | | [6] | [8] | [7] | | [9] | [11] | [1] |

**Table 5.** Reinforced COVID-19 infectious medical waste management measures compared to current regulations.

| Category | Discharger Storage | Transport | Treatment |
| --- | --- | --- | --- |
| Current regulations on infectious waste | • Store for up to 7 days<br>• Designated synthetic resin container<br>• Refrigerate only tissue waste<br>• Disinfect storage warehouse | • Refrigerated transport<br>• Temporary storage (2 days) | • Treatment time: 2 days |
| Reinforced COVID-19 infectious waste management | • Same-day outsourced treatment (within 1–2 days)<br>• Refrigerated storage in principle<br>• Disinfect before and after putting in a dedicated container | • Temporary storage prohibited with same-day transport<br>• Disinfect vehicle after every use | • Same-day incineration |

Table 6 summarizes the treatment status and methods used for the management of COVID-19 infectious waste in each country. As part of its COVID-19 countermeasures, in May 2020, the Japanese Ministry of Environment distributed waste treatment guidelines for households, medical institutions, and other businesses. As per the guidelines, places of waste generation are divided into (i) "general households or businesses" (excluding (ii) and (iii)); (ii) "medical institutions and research and testing facilities."; and (iii) "lodging and care facilities." The ministry recommends following the novel influenza guidelines for waste treatment published in 2009. The influenza waste classification distinguishes between waste discharged from general households or businesses, waste discharged from medical-related institutions, and medical waste discharged from lodging and care facilities.

In the UK, due to the recent spread of COVID-19, there are concerns that the virus may spread through face-to-face contact when disposing of and collecting waste. In addition, because the waste may be contaminated with the virus, the UK has closed many Household Waste and Recycling Centers (HWRCs), in addition to the implementation of lockdown measures. Accordingly, the UK Department for Environment, Food & Rural Affairs (DEFRA) provided guidelines for operating HWRCs during the pandemic. The Health Protection (Coronavirus) Regulations 2020 in the UK designated HWRCs as "waste or recycling centers." According to the DEFRA guidelines, there is no legal basis for closing HWRCs, and such decisions rest entirely upon local authorities, depending on the availability of resources in each region and the spread of COVID-19 [18]. While the central government's comprehensive opening/closing guidelines are not considered fit as a flexible response to the current situation, it includes a proviso that an HWRC may be closed only in the case of concerns about the safety of staff who operate the HWRC. When a local government reopens an HWRC, the type of waste that can be treated must be disclosed online. Furthermore, since HWRCs differ in location, form, waste capacity, and demand and must also consider obtaining other legal requirements (e.g., Public Sector Equality Duty), the operation and resumption plans must reflect the views of local stakeholders (e.g., local police, waste disposal officials, HWRC workers, and staff). The government also guides the prioritization of the types of waste to support waste treatment during the pandemic [17]. The recommendations described are laid down for the local governments and waste companies; while the recommendations may not be suitable for the local government's circumstances, the authority's highest duty is to protect the health of the workers and residents, for which it must consider the recommendations of the guidelines. There are three levels of priority services. "High priority" services are the most important, as they include services that must continue as normal and are legally mandated, a complete delay in which would lead to large environmental and health impacts. The next level is "medium priority": if such services are stopped, there will be some confusion, but the impact will not be as severe as delaying high-priority services. "Low priority" level corresponds to services expected to have minimal to no impact upon being delayed, as well as for which negligible or almost no health risk is expected upon stopping.

**Table 6.** Comparison of COVID-19 medical waste treatment status and methods in each country reviewed.

| Country | ROK | Japan | UK | USA | China |
| --- | --- | --- | --- | --- | --- |
| Governance | Government-led waste treatment | Government-led application of existing novel influenza guidelines | Decided by local governments | Guidelines of private companies | Decided by local governments under the guidance of the central government |
| Content | • Reinforced management measures compared to existing regulations<br>• Same-day outsourced treatment/transport/incineration<br>• Disinfect in each process from discharge to treatment<br>• Treat municipal waste identically to infectious medical waste (disinfection, same-day treatment, etc.)<br>• Classified into infectious medical waste, residential treatment center waste, waste from self-quarantine patients, waste from places visited by confirmed patients, and waste from multiuse facilities | • Different treatment guidelines for each waste generation site<br>• Designated containers according to waste characteristics<br>• Classified as lodging and care facilities such as general homes, businesses, and medical-related institutions | • Proposed management plan according to waste type priority (including health risks); high priority, medium priority, low priority.<br>• High priority: General waste and food waste.<br>• Medium priority: dry recyclable waste (collected biweekly), household waste, and waste sent to recycling center (HWRC)<br>• Low priority: dry recyclable waste (collected weekly), garden waste, bringing sites, and bulky items. | • State-specific solid waste regulation programs<br>• No separate designation for waste hazards according to infection characteristics<br>• Treated as municipal waste except in special cases<br>• Management guidelines on treating COVID-19 waste provided by private organizations and companies<br>• Producers of the waste responsible for packaging it. Collection refused if improperly packaged. | • Ministry of Ecology and Environment and the National Health Commission in terms of medical waste management during the COVID-19 pandemic |

The US has no special government-level guidelines for treating COVID-19 waste, but it recommends treating such waste in line with existing procedures. The Resource Conservation and Recovery Act (RCRA) provides a system for properly managing hazardous and non-hazardous solid waste. General solid waste, including medical and infectious waste, should be managed according to each state's solid waste regulation program. The programs may change between states. RCRA does not define waste hazards according to the characteristics of infection including the infection caused by the novel severe acute respiratory syndrome coronavirus 2 although the EPA has established air emission standards for treating "hospital/medical/infectious" waste in solid waste incinerators [20]. The Centers for Disease Control and Prevention recommends that medical waste generated from the treatment of COVID-19 patients and patients under investigation be managed according to existing federal and state procedures without establishing new regulations or guidelines. Initially, some states recommended that waste produced by patients be classified as waste requiring special treatment (e.g., disinfection before being landfilled); afterward, however, it was mandated to treat only certain waste produced from equipment or medical facilities contaminated with body fluids, with the rest being treated as municipal waste.

### *3.4. Implications and Directions for Medical Waste Management in Korea*

Although Korea's current medical waste management system can be described as highly advanced, an inadequate understanding of the risks of medical waste remains. Since 2008, the Ministry of Environment has devoted extensive efforts to reforming laws and systems and providing on-site guidance to establish a new system. Nevertheless, it is now crucial to reach a social consensus for the management of medical waste because the generation of medical waste is rapidly growing annually, and the capacity of incinerators dedicated to medical waste treatment is nearly saturated. Figure 1 presents three approaches to addressing this situation: the first is to reduce the amount of medical waste generated, the second is to secure sufficient capacity for incinerators dedicated to medical waste as soon as possible, and the third is to diversify medical waste treatment methods. Among these, only the second approach is being implemented currently. It will be challenging to keep up with the accelerating generation of medical waste through this approach alone; given that incinerators gradually degenerate, it is difficult to serve this as a fundamental solution. As such, it is necessary to simultaneously consider methods to reduce the amount of medical waste generated and diversify treatment methods. Even among the countries examined earlier, opinions varied on how far the scope of medical waste requiring special management should extend and what treatment methods should be applied for them. As such, the three aforementioned approaches require a comprehensive review.

#### 3.4.1. Reduction of Generation

Establishment of a Separate Medical Waste Collection System

The most basic principles in waste management are to prevent or reduce the generation of waste and to reuse or recycle generated waste as much as possible. In most Korean hospitals, there are insufficient efforts to thoroughly separate medical waste from municipal waste and reduce the amount generated. As municipal waste mixed with medical waste is treated as medical waste in principle, if it is not properly separated and collected, the amount of mixed waste may increase. According to an online survey of 126 general hospitals in a prior study, 29 hospitals (23%) disposed of medical waste in municipal waste containers and 66 (55%) disposed of municipal waste in medical waste containers.

Review of the Medical Waste Classification System

Authorities may consider excluding certain solid general medical waste with a very low probability of infection from the medical waste category. For this purpose, a comprehensive assessment of systematic risk is necessary. Many states in the US exclude items corresponding to domestic general medical waste from the category of Regulated Medical Waste. In Korea, there are growing requests to exclude some disposable diapers the most

common general medical waste from elderly care facilities from the category of medical waste. In the long run, authorities can also consider excluding certain chemical waste other than vaccines among biological and chemical waste and certain types of general medical waste. As placing chemicals included in medical waste into the incinerator in a sealed state causes explosions, their exclusion from medical waste should be considered. Such explosions during incineration are a potential hazard to workers and may adversely impact the incinerator's life.

Efforts to Improve the Accuracy of Generation Statistics

In Korea, the calculation of waste generation using the radio-frequency identification electronic system has become more accurate than in the past. Nevertheless, as contracts between the dischargers and treatment companies often use a flat rate rather than a variable rate according to the amount generated, it may still be impossible to obtain accurate generation statistics. Future policy directions should be based on accurate and improved generation and treatment statistics; moreover, calculating treatment costs of medical waste based on the amount generated will likely contribute to more accurate statistics and incentivize the discharger to voluntarily separate and collect waste. The UK commonwealth of Wales should be referred to regarding the cost of outsourced treatment. In the 1990s, hospitals in Wales formed the Wales Shared Services Partnership–Procurement Services, thereby standardizing the pricing system in Wales. This aimed to provide all hospitals with the same medical waste treatment process regardless of region and size and was applied so that rather than individual hospitals, the association collectively makes transactions with treatment companies.

3.4.2. Diversification of Medical Waste Treatment Methods

Sterilization Grinding Treatment

Thus far, Korea has adopted a unified treatment method of outsourced incineration. Given that the School Health Act prohibits waste treatment facilities within 200 m of school boundaries, it is difficult to install on-site treatment facilities for economic reasons. While incineration is a reliable treatment method from a management perspective, all domestic medical waste treatment has been outsourced to certain companies; thus, diverse on-site treatment methods must be actively considered.

Various technologies have been developed for treating medical waste on-site and can be introduced once safety is secured and economic conditions are satisfied; for instance, the recently developed sterilization grinder has made much progress in terms of cost-effectiveness compared to previous technologies. Accordingly, on-site treatment technologies should be selectively introduced through systematic assessments. Given the difficulty of building more incinerators in Korea due to the country's small area compared to other nations, the proportion of on-site treatment should increase, and the dependence on incineration should be reduced; hence, the School Health Act must be amended. In this case, regulations can individually stipulate whether on-site treatment is permitted for each type of medical waste. For example, on-site treatment can be limited to general medical waste, sharps waste, and pathological waste. In the EU, non-hazardous medical waste is treated identically to municipal waste, while infectious waste and sharps waste may be subject to sterilization. Accordingly, it is also necessary to apply methods that use sterilization techniques, depending on the type of waste in Korea, even if HRMW such as infectious medical waste is treated via outsourced incineration.

Using Incinerators Not Dedicated to Medical Waste

Treatment using municipal waste incinerators can be considered if the residues after sterilization and grinding are deemed safe or relatively safe through risk assessment. Current regulations mandate that the residues after sterilization and grinding be incinerated at designated waste incineration facilities; however, authorities should review the use of municipal waste incinerators when necessary, after assessing risks and economic feasibility.

As general medical waste carries a lower risk than infectious and hazardous medical waste, the government may consider permitting treatment in incinerators other than those dedicated for medical waste, under the condition that a closed dedicated container is used. Since general medical waste comprises approximately 80% of medical waste in Korea, in practice, it would be preferable to apply this approach to only some types of general medical waste on a trial basis. Additionally, rather than the type of medical waste, measures applying different standards depending on a specific condition (e.g., when the amount of generated waste exceeds the incineration capacity) or the type of discharge facility can also be considered. For such policies, however, it would be essential to gather opinions from the relevant stakeholders and adequately communicate the risks involved.

## 4. Conclusions

This study identified the strengths and weaknesses of the current medical waste management system in Korea and proposed measures for establishing an effective management system based on contemporary information about the medical waste management systems used in Korea and those used globally. Examples of the representative advantages of the medical waste management system used in Korea are as follows. Regulations related to medical waste are managed at a strict level compared to other countries, and chemical treatment methods for medical waste treatment are introduced, which has the advantage of shortening the treatment time of medical waste. In Korea, measures for efficiently managing medical waste from discharge to treatment have been adopted since 2008; however, numerous issues have been raised since the early 2000s, such as a rapid increase in the generation of medical waste, difficulty in securing enough dedicated incinerators, regional imbalances between generation and treatment, and swift and safe treatment in the event of an epidemic. One may argue that Korea's broad definition of medical waste and its active waste regulation and management is preferable; however, most medical waste is currently treated via dedicated, outsourced incineration, and the rapid increase in medical waste and the difficulty of expanding incineration capacity are pushing the current waste disposal system to its limit. As such, it is necessary to compare data with those of other countries and devise a multi-dimensional approach to resolve current problems, ranging from efficiently classifying medical waste to reducing its generation and diversifying treatment methods.

**Supplementary Materials:** The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su14063678/s1, Table S1: Classification of hazardous medical wastes, as per the Republic of Korea; Table S2: Comparison of regulations regarding medical waste management methods such as discharge/container, storage, transport, and disposal.

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