HIGH SCHOOL EDITION
Journal of Student Research
Volume 11 Issue 4 (2022)

A Review of Current and Novel Methods of Medical Waste Management

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ABSTRACT

According to the World Health Organization (WHO), high-income and low-income countries generate on average up to 0.5 kg and 0.2kg of hazardous waste per hospital bed per day, respectively. However, hazardous waste only accounts for 15% of total medical waste. The amount of total medical waste has increased over time, especially with medical supplies ordered during the COVID-19 pandemic. The purpose of the paper is to increase awareness of the problem regarding the difficulties of medical waste management and discuss possible solutions to these challenges. This review will inquire into the various methods of medical waste management, their current statuses, and their environmental, economic, and social impacts. Types of medical waste include pharmaceutical, blood/blood related products, sharps, body parts/tissues/organs, contaminated equipment, and COVID-19 products. The author describes in detail the environmental, economic, and social implications of the use of landfills, incineration, steam sterilization, sewage, and common forms of improper disposal, during which the author discusses impacts such as leaching and social disparities faced by developing countries. The author also considers economic and environmentally friendly medical waste management such as redistribution of medical supplies to vet clinics as well as innovative medical waste management technologies including thermal plasma treatment and plasma pyrolysis. The author suggests that medical waste management focuses on economical methods that have small environmental impacts and large social benefits such as methods of redistribution.

Introduction

According to the World Health Organization (WHO), high-income countries generate on average up to 0.5 kg of hazardous waste per hospital bed per day and low-income countries generate on average 0.2 kg. However, hazardous waste only accounts for 15% of total medical waste(*Health-Care Waste*, n.d.). Waste generated through healthcare activities includes those from hospitals, vet clinics, and pharmacies(US EPA, 2016). The United States Environmental Protection Agency (EPA) regulated medical waste through the Medical Waste Tracking Act of 1988. However, this act expired in 1991(US EPA, 2016). In the United States, medical waste is now regulated by individual states, other federal agencies such as the Centers for Disease Control (CDC), Occupational Safety and Health Administration (OSHA), U.S. Food and Drug Administration (FDA), and others(US EPA, 2016).

The amount of medical waste has generally increased over time. This is reflected in the rapid projected growth in the global medical waste management market from 7.2 billion USD to an estimated 12.8 billion USD by 2030(Ltd, 2021). With COVID-19, the rate of increase in medical waste has accelerated. For example, there was a 5.4% increase in the number of sharps (i.e., needles) waste generated per year in the recent two years(News & Rajput, 2021).

This review will inquire into the various methods of medical waste management. The types of different medical waste and their current statuses will also be meticulously discussed. The environmental, economic, and

social impacts of medical waste management are discussed. The purpose of the paper is to increase awareness of the problem regarding the difficulties of medical waste management and discuss possible solutions to these challenges. The investigation on this topic is crucial for medical waste management as the amount of medical waste increases each year(Tsai, 2021) and is worsening with the COVID-19 pandemic .(Sarkodie & Owusu, 2020)

Types of Medical Waste and Current Practices

Pharmaceutical Waste

Pharmaceutical waste includes expired, unwanted, or contaminated medications or drugs(Kadam et al., 2016). As pharmaceuticals are designed to have a biochemical impact on humans, even low concentrations can adversely impact the natural aquatic environment through endocrine disruption and bioaccumulation(Ternes, 1998). The United States spends over $1 billion on drug wastage(Kadam et al., 2016).

The disposal process of pharmaceutical waste may vary for the specific drugs. Proper disposal of unwanted pharmaceuticals includes drop-offs at the pharmacy or drug producer site where the pharmaceuticals may be securely incinerated and destroyed(Research, 2021). However, in a survey of 500 people, approximately 89.4% of participants had disposed their expired medications in landfills/garbage or flushed them down the toilet/drain(Kuspis & Krenzelok, 1996), practices that are discouraged because of the potential environmental health risks(Commissioner, 2021). Figure 1 depicts the possible pathways of pharmaceutical waste disposal.

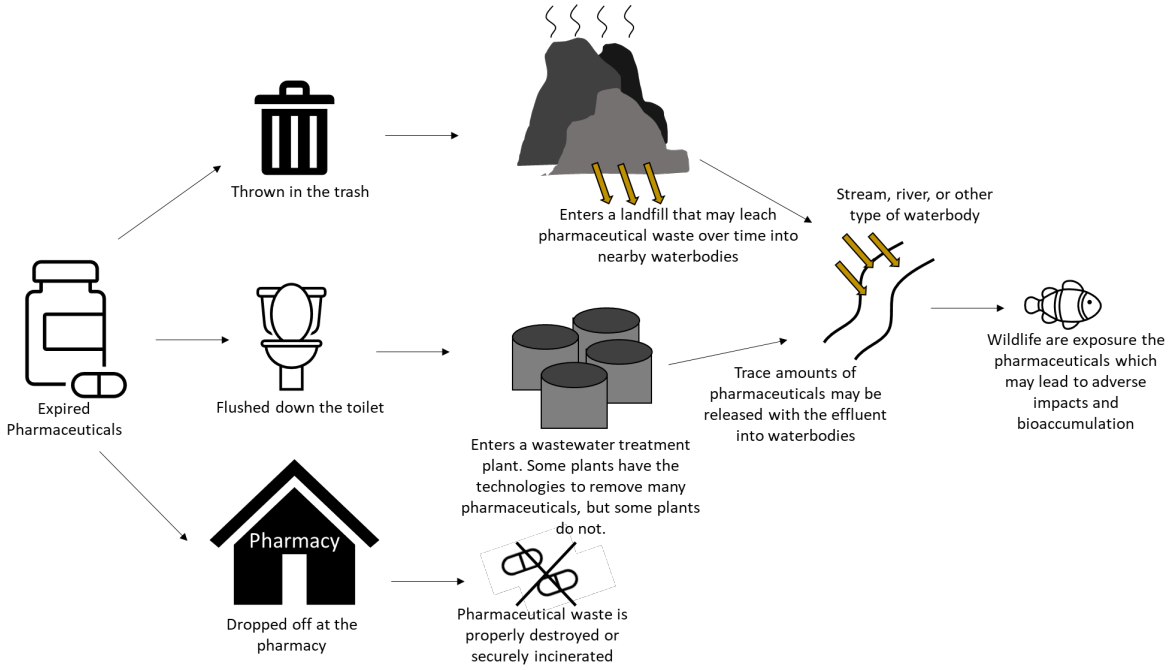

Figure 1. Potential pathways of expired pharmaceutical waste

Blood and Products Related to Blood

Blood is an essential resource of the medical system. It is used in medical procedures such as transfusion.(Stanger et al., 2012) However, the disposal of blood and products contaminated with blood make up a large portion of total medical waste. Improper disposal of blood and contaminated projects may increase the risk of infection

of blood transmissible diseases for healthcare professionals and those handling the collection, transport, and disposal(Shiferaw et al., 2012).

The disposal process of these waste products is extensive. For example, procedures such as steam sterilization or incineration are often used to safely dispose of blood waste and products contaminated with blood such as cryoprecipitate or platelets(Akter, 2000). Although there is a rise in the number of hospitalized patients who require blood transfusion or dialysis, (*Blood Safety and Availability*, n.d.) the amount of red cell blood usage has been decreasing over the years.(Hoeven et al., 2016) We speculate that this is because medical technologies and practices (i.e., blood transfusion) have improved and become more efficient and therefore may require less red blood cell supplies.(Hoeven et al., 2016)

Sharps

Common sharps used in hospitals include needles, syringes, lancets, and auto injectors("What Are Sharps?," n.d.). These materials are defined in Table 1.

There has been a decrease in the injuries from sharps wastes in the United States from approximately a million people to 400 thousand people per year (*The Historical Trends and Improvements in Sharps Injuries*, 2017). However, this is not from the decrease in the actual number of sharps but rather an improvement in the awareness of safe disposal of sharps waste. Prior to 1980, when there was low awareness of the importance of throwing out sharps well, sharps were improperly disposed of, leading to workplace injuries and infections(*The Historical Trends and Improvements in Sharps Injuries*, 2017). Now, safety disposal boxes, steam sterilizations, and incinerations are used to minimalize physical injury and infection of employees(Akter, 2000).

Table 1. Definitions of common sharps used in hospitals("What Are Sharps?," n.d.)

Needle	Syringe	Lancet	Auto Injector
• Slim piece of hollow metal. • Shape may vary in increments, but most are long and straight. • Most used to inject liquid medication under the skin.	• Often used with a needle for injection of medication. • May be used to measure fluids to be injected into or removed from the body.	• A small two-edged blade poked into a finger to bring out small drops of blood. • Often used by diabetics to test blood sugar levels.	• Product in the form of a syringe filled with liquid medication for self- administering. • Commonly used to self-inject epinephrine

Body Parts, Tissues, and Organs

Body parts waste, also known as anatomical waste, refers to limbs and organs. Limb and organ waste are common after replacement surgeries, childbirth (i.e., placenta)("Anatomical Waste Management," n.d.), and biopsy specimens, tissues, and skins grafts from lab tests. Because these wastes are biological, they are not processed in the same way as general non-biological waste("Anatomical Waste Management," n.d.).

In 2011, Thailand reported that about 386 grams of body parts waste were produced daily per bed from a single hospital(Adsavakulchai, 2002).

Tissue and organ transplants are often a last resort for patients with irreversible conditions.(Grinyó, 2013) Organ or tissue transplants are often done to extend a patient's life or improve the patient's quality of life(National Academies of Sciences et al., 2017). Well-functioning organs taken from live or deceased donors

are used as transplants. Unused donor parts as well as the original malfunctioning tissue or organ that was removed from patients also become medical waste.

Contaminated Equipment

In hospitals, equipment is often contaminated even with efforts to keep it sterile. This is due to microorganisms extant in the air as well as the inevitable infection of bacteria when in contact with a patient(Obasi et al., 2009). Commonly contaminated equipment may include(Borders, 2019):

1. Hospital stretcher – equipment used to carry personnel around
2. Stethoscope – tool that measures heart rates and allows the doctor to check on the pattern
3. Scalpel – surgical knife used to make openings in the body
4. Thermometer – apparatus used to measure temperature of person
5. Cast saw – saw used to sever cast
6. Weighing scale – used diversely to measure weight of objects or medicine for appropriate use
7. Defibrillator – device that gives electrical shock to the heart to vitalize it

Some equipment such as scalpels or stethoscopes can be sterilized again using a sterilizer and thorough wiping with alcohol pads(Obasi et al., 2009).

COVID-19 Products

The COVID-19 pandemic that was introduced in late 2019 called for more medical products such as masks, gloves, and ventilators due to the sudden surge of ill patients. Many countries introduced mask mandates resulting in the large increase in production, use, and disposal of medical masks(*These Are the States With Mask Mandates During the Coronavirus Pandemic | Best States | US News*, n.d.).

In 2021, Lebannon created nearly 1.3 tons of infectious waste related to COVID-19 every day(Maalouf & Maalouf, 2021). The medical wastes include masks, needles, syringes, and even daily items that were used with an infected patient. In other words, COVID-19 medical wastes include everything that comes in to contact or has existed in the same space as a patient. Since these wastes are infectious and the virus is known to be highly contagious, the usual route to dispose these wastes would be to incinerate them or bury them deep. Between these two options, incineration is more common because it is quicker and more effective(Maalouf & Maalouf, 2021).

Additional pharmaceutical waste such as vaccines were added during the COVID-19 pandemic. Sincne March 1, 2021, around 15.1 million vaccines have been thrown out due to expirations and damages(Murphy, 2021). Diluted vaccines are thrown out to various locations such as the sewage, the landfill, etc. In addition, the COVID-19 vaccine containers/viles are disposed of in landfills after sterilization and elimination of vaccine fluid(Murphy, 2021).

While the trend for the amount of COVID-19 products is irregular and not accurately predictable, (Maalouf & Maalouf, 2021). future COVID-19 medical waste may be determined by the number of people infected by the virus in the future.

Impacts of Medical Waste Management

The author considers the environmental, economic, and social impacts of medical waste management techniques. In this section, we will describe in detail some of the environmental, economic, and social implications of the use of landfills, incineration, steam sterilization, sewage, and common forms of improper disposal.

Landfills

Major environmental impacts of landfills include leaching and greenhouse gas emissions. Chemical reactions may take place in landfills and release various types of toxins such as mercury and cadmium("What Is a Landfill?," 2020). Leaching is the process of toxins permeating through the soil and water and tainting the land("What Is a Landfill?," 2020). Another environmental issue regarding landfills relates to the large amount of space they inhabit, often an inhospitable environment from many biodiverse organisms("What Is a Landfill?," 2020). In the United States, 292.4 million tons of municipal solid waste is produced per year(Deer, n.d.). Landfills may be cheaper than other types of disposals(*What If the U.S. Put All Its Trash in One Giant Landfill?*, 2008), but still have large costs of $32,000* to $162,000 per acre and maintenance costs of $4,000 per acre. In the US, there is approximately 160,000 acres of landfill space. As mentioned, landfills are often affected by leaching, contaminating the land contaminated for a prolonged amount of time(*What If the U.S. Put All Its Trash in One Giant Landfill?*, 2008). This signifies that is it unlikely that the land once occupied by landfills can be used for other purposes. Additionally, landfills are a social justice issue. There is a decrease of 12.6% (US standard) in the value of nearby lands and properties when a landfill is formed because there is a sanitary hazard.(*The Hidden Damage of Landfills*, 2021) With landfills, there is also an international social impact because wealthier countries have historically exported landfill waste to poorer developing countries such as Philippines, Vietnam, and Thailand, where there is no proper landfill waste treatment avaliable (Varkkey, n.d.). The effects of pollution are directly received by the residents of these poorer countries (Varkkey, n.d.).

Incineration

An environmental impact caused by incineration is air pollution from chemicals such as dioxin that are released into the air during the incineration process of medical waste(Sharma et al., 2013). Previous studies report that air pollutants created from the process of incineration are associated with hormonal changes in the body as well as the sex ratio of newborns of residents within 15km of the incineration site(Sharma et al., 2013). Incineration is one of the most expensive ways to handle medical waste(*Trash Incineration Is the Most Expensive Way to Manage Waste | Energy Justice Network*, n.d.). It is reported that one ton of waste costs $1000 to dispose and that a single small sized incinerating plant costs $41 million to construct(Gergel, 2015). The social impact of incineration is like that of landfills. There is a focus of incinerators in remote areas with lower land price and more minorities/low-income persons(Incineration, 2000).

Steam Sterilization

Steam sterilization requires a tremendous amount of energy and water. For instance, 326,52kWh of electricity and 1,243,495L of water are used for active cycles of steam sterilization. While in standby, the sterilization consumes 21,457kWh and 329,200L of water(McGain et al., 2017). While there are various types of sterilizations, steam sterilization is one of the most affordable options sterilize medical equipment at $300 per unit(Adler et al., 1998). The majority of costs are for energy demands, (Adler et al., 1998). There are limited studies discussing the health impacts of steam sterilization. However, a few previous studies indicate that the employees who work closely with steam sterilizers may be exposed to burns or metal poisoning(Tankeshwar, 2013).

Sewage

In study that surveyed respondents on their medication disposal practices, 27.2% of respondents frequently flushed medications down the toilet(Abrons et al., 2010). Another survey conducted by the Federal Drug Administration (FDA) and Environmental Protection Agency (EPA) revealed that 35.4% of their survey respondents commonly flushed their medications down the toilet or sink(Moral Pajares et al., 2019). However, only a limited number of drugs can be disposed through flushing or draining(Research, 2021). Studies have revealed that drugs flushed or drained to the sewage system can contaminate effluent waterbodies, disrupting the reproduction and growth of many aquatic species(*Don't Flush Medicines down the Drain*, 2013) (*Drugs in the Water*, 2011). Though flushing expired medications may relieve the patient from excessive disposal cost burdens(Hoeven et al., 2016), wastewater treatment plants often operate at a financial loss due to the high costs of the wastewater treatment equipment and high volumes of sewage(Moral Pajares et al., 2019). However, a survey in 2006 of outpatients found that under 20% had received instructions about how to properly disposal of their medication(Seehusen & Edwards, 2006). Researchers highlight the importance of education for patients and clinicians who are not aware of proper medical disposal(Athern et al., 2016). However, patients had reported flushing their expired medications down the toilet because of ease or to avoid the inconvenience of having to return to the pharmacy, a feat that may be most difficult for groups such as the elderly and/or disabled(Abrons et al., 2010).

Improper Disposal

The EPA and FDA describes the proper methods of disposal of different types of medical waste products. Certain types of medical waste are more strictly regulated because of their potential harm when improperly disposed of(Research, 2020b) due to the possible mal environmental, economic, and social impacts that may result. For example, improper disposal of certain types of medication and solutions(Research, 2020a) in landfills and/or the drainage system may lead to contaminated water supplies, impacting both public health and wildlife("What Is a Landfill?," 2020). Additionally, improper disposal of sharps may lead to injury and illness, especially if the sharp was contaminated with infectious medical waste(*CDC - Bloodborne Infectious Diseases - Stop Sticks*, 2019). The economic burden of addressing the environmental and social impacts of the improper disposal of medical waste after-the-fact may exceed the economic cost of proper disposal methods.

Novel Methods of Reducing Waste

Redistribution

An important and underused method of reducing medical waste is redistribution. Redistribution describes the process of reorganizing medical supplies from organizations/hospitals/clinics that have a surplus towards organizations/hospitals/clinics that are lacking. (*Definition of Redistribution | Dictionary.Com*, n.d.). Redistribution is a economical and environmentally friendly method of dealing with a surplus of perishable medical supplies. In addition, redistribution provides social benefits to the international and local community by providing small businesses, non-profit or foreign service organizations materials for their practices.

For example, Project V.E.T.S (Veteritanry Equipment Technology and Supplies), located in Boulder, Colorado, is a group that redistributes medical equipment from a variety of organizations such as hospitals, non-profits, and colleges and distribute them to veterinarians all over the world(*General 1*, n.d.). Their mission is to aid animals around the world that die because of medical equipment shortage while also reducing the medical waste produced at hosptials.(*General 1*, n.d.) The project targets helping third world countries that do

not have the same access to medical products as rich countries such as the US. (*General 1*, n.d.) Since 2004, when their project commenced, the organization has reached multiple parts of the world such as Uganda and Nigeria to assist veterinary clinics in helping pets, livestock, and street animals. Medical supplies that were redistributed towards this cause may have been otherwise disposed of.

Another project that has been utilizing the redistribution method for reducing medical waste is the No Fog; Go Dog project by The Symbiotic People. The Symbiotic People is a group composed of high school students located in Vancouver, Canada that specifically targets hospitals and vet clinics("The Symbiotic People - No Fog; Go Dog!," 2020). The group also has interational members, including the author, who aids in communicating with organizations across the globe. Local organizations, Langley Hospital and Alpha Animal Hospital, were redistribution participants. Items that were given to the vet clinic were alcohol wipes, biopsy needles, and ivy drips (Figure 2). As a result, The Symbiotic People was able to reduce a dozen boxes of soon-to-be throw out medical products over the course of 6 months and redistribute them over to vet clinics("The Symbiotic People - No Fog; Go Dog!," 2020). Lastly, this group was able to make social impacts as well by opening social media accounts that included details of the project. This report that was published was viewed by numerous peers and adults as a source of inspiration and a way to raise awareness about the medical waste situation.

Figure 2. Examples of medical supplies that were redistributed to animal hospitals and clinics during the No Fog; Go Dog project in Vancouver, Canada. (a) Alcohol wipes, (b) Biopsy Needle, and (c) Ivy drip. Photos were taken by the first author.

Innovative Technologies

Many technological advancements have occurred that may have different impacts than traditional methods of medical waste management.

For example, the thermal plasma treatment method is a method of managing medical waste by emitting high energy plasma to melt it(Gomez et al., 2009). This method is beneficial because it occupies smaller space than incinerators or landfills, runs rapidly, and causes less pollution(Cai & Du, 2021). While the specifics of the technology are not perfected yet, many of the thermal plasma treatment machines are being developed to be deeployed in a few years.

Plasma pyrolysis is another new technology that converts biomedical and organic waste into commercially usable products(Nema & Ganeshprasad, 2002). The heat from the plasma melts the waste but the temperature of the plasma is cooled instantly to prevent further recombinations of harmful chemicals. Thus, a reusable product is created by the plasma.

Recommendations for the Future

The current methods such as incineration, sewage, and landfill are not sustainable over a long period of time. One of the simplest methods of reducing medical waste is through redistribution, as mentioned above. As medical supplies are appropriately redistributed, less will likely go to waste. While a few organizations around the world lead redistribution projects, redistribution is still an uncommon practice. However, redistribution is simple, economical, has limited economic impacts, and provides opportunities for various local and international organizations to connect, communincate, and educate.

Additional research and engineering fleets to create novel medical waste management techniques and improve existing techniques are essential. For instance, the addition of HEPA air purifiers/filters to incinerators have helped decrease air pollutants during the incineration process(*Incineration Air Purifier*, n.d.). However, additional research is needed to increase the filter effectiveness and efficiency.

An important method of reducing medical waste is through social influence. Many people are simply uneducated about the existing amount of and proper disposal of medical waste. The author believes that clinicians and pharmacists should have the responsibility stay informed and to educate their patients on the impacts of medical waste on the environment and the methods of reducing negative impacts(Seehusen & Edwards, 2006). The author also recommends increasing the community's ease in proper medical waste management practices such as by distributing pharmaceutical waste bins throughout.

In conclusion, current methods of medical waste management have many negative environmental, economic, and social implications. This study intended to increase awareness of the medical waste management problem and discuss possible methods of management that have less negative environmental, economic, and social impacts such as redistribution.

Acknowledgments

I would like to thank my advisor for the valuable insight provided to me on this topic.

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