Bioplastics as a Solution for Plastic Medical Waste

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Author

Wyatt Black

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

Signed: ______Wyatt Black____

Approved: _______________________________________ Date _______________________
Rider Foley, Department of Engineering and Society

Introduction

In today's hospitals, single-use plastics are seen everywhere from syringes, gloves, medical device packaging, pipets, and bandages. They are an integral part of the healthcare system and provide a vital role in the prevention of the spread of bacteria and infectious diseases (Gibbens, 2019). However, since they are considered a biohazard in the United States (US), they are required to be incinerated or sent to special landfills (WHO, 2000). These unsustainable practices have led to increased amounts of medical plastic waste contributing to damage to the environment.

A catalyst for the adoption of single-use plastics occurred in the 1980s and 90s during the peak of the HIV/AIDS pandemic (North, 2013). Hospitals looked to find an alternative to metal syringes that would be washed between patients. Single-use plastics were able to provide that security. They are cheap, easy to manufacture, germ-resistant, and easy to sanitize (North, 2013). Above all else, they are disposable and can be thrown away after use. Since then, they have become commonplace, but after years of throwing plastics away, the consequences are just beginning to emerge. This plastic waste build-up is only exacerbated by events like the COVID-19 outbreak and the Chinese “National Sword” policy. In 2020, the outbreak of COVID-19 caused an increase in single-use plastics due to the fear of transmission of the virus. The US generated an entire year’s worth of medical waste in two months because of the impact of COVID-19 (Cutler, 2020). More plastic will continue to accumulate due to the enaction of China’s “National Sword” policy, which reduced their import of US plastic waste by 99% (Katz, 2019). All of these factors combined lead to medical waste piling up with no way to deal with it and these plastics end up just being burned or buried.

This paper will explore the validity and implementation of biodegradable bioplastics into the medical industry in hopes of providing hospitals with materials that meet medical standards while not contributing to the growing plastic crisis.

Case Context

Environmental Harm

Plastics that are discarded in landfills or incinerated cause problems for the environment no matter the source. As time goes on, their negative effects only begin to compound and get worse. When plastics are irresponsibly dealt with, they can leach toxins into the air, water, and soil. In the case of incineration, plastics like PVC, a common single-use medical plastic, can lead to dioxin, lead, and mercury being released into the environment (Okafor, 2018). Improper landfill containment can leach compounds like bisphenol A (BPA) and di-(2-Ethylhexyl) phthalate (DEHP) into groundwater (North, 2013). These compounds can lead to complications including cancer, insulin resistance, and damage to reproductive systems (North, 2013). If not in a landfill or burned, plastics can find their way into waterways and lead to partial decomposition and the creation of microplastics. These microplastics can carry harmful compounds via drinking water or cause damage to marine life (Okafor, 2018).

The medical industry is responsible for some 850 million pounds of plastic waste per year, most of which is incinerated or landfilled due to the fear of downstream contamination when recycled (North, 2013). The problem is that almost 85% of medical plastic waste can be cleaned or recycled but the status quo is to just burn or bury it (WHO, 2000) This occurs because the recycling programs and autoclaving techniques, which sterilize and shred plastics, are too expensive or too labor-intensive for most hospitals (WHO, 2000) This problem isn’t across all hospitals worldwide; the US has the highest amount of plastic waste coming in at 8.4 kg/bed/day (Minoglou, 2017) When compared to Europe, the US has about double the amount of waste, even over the most wasteful country of Spain coming in at 4.4 kg/bed/day (Minoglou, 2017). Operating rooms are among the biggest problems, amounting to about a third of hospital waste that includes items such as IV tubing, syringes, packaging, gowns, and single-use plastic surgical tools (Glauser, 2016). Some procedures can have upwards of 20 pounds of waste (Gibbens, 2019). This massive scale of US plastic waste is a combination of a couple of underlying factors, such as high GDP, high life expectancy, high healthcare expenditure, high AIDS prevalence, and high C02 emissions (Minoglou, 2017). Overall, the US creates more medical waste than any other country and if something doesn't change, irreversible environmental damage will occur.

Polyhydroxy Butyrate and Bacteria Cellulose

Polyhydroxy butyrate (PHB) is a novel bioplastic that can degrade anaerobically in the environment. This paper plans to explore the implementation of this bioplastic in hospitals in the form of single-use medical products like syringes, surgical tools, IV tubing or medical packaging. However, bioplastics can't just be thrown anywhere and then be expected to fully decompose. The crystalline network, the addition of plasticizers, environmental conditions such as temperature, humidity, and the presence of microorganisms all affect the degradation of these plastics (Naranic et al., 2020). Each material requires certain parameters to undergo full degradation. Therefore, new recycling programs and training will also need to be introduced if this product is to be successful. If the PHB was to be used as a medical device and not packaging, there will also have to be biocompatibility testing to ensure that the plastic doesn't elicit a free body response or other negative consequences. The second biomaterial for this project is a paper that is made from a bacteria cellulose (BC) derived from the live culture that is used to make kombucha. Its innovation comes in the form of using cellulose, an abundant organic building block, to form sheets that can act as paper. The process uses transparent BC film made via hierarchical alignment from molecular level crystalline cellulose chain alignment to microscale level fibrils bundle alignment (Wang et al., 2018). The end product is a film that is aligned, tough, and flexible. This paper is also biodegradable and can be used with other products. This paper would most likely be used as the packaging for a PHB instrument. There is also the possibility of combining the two together to create a hybrid biomaterial. This material would be designed to be fully biodegradable and could be customized for different applications.

Alternative Solutions and Proof of Concept

PHB isn't the first bioplastic on the market today. The forerunners in the field include Polylactic acid (PLA) and Polyhydroxyalkanoates (PHA) (Naranic et al., 2020). Both of these bioplastics are already viable for use by hospitals and exhibit both biocompatibility and biodegradability. They also have melting temperatures and glass transition temperatures that are similar to traditional plastics, making them mechanically viable for replacements (Bano et al., 2017). These plastics are already being used in the medical industry ranging from tissue scaffolding, drug delivery, and packaging replacements (Naranic et al., 2020). This shows that PHB could be used in the medical industry, and the other bioplastics offer alternatives and proof of concept. There are also companies that are creating more sustainable and reusable medical devices. Companies including, EnviroPouch and NewGen Surgical already produce reusable sterilization pouches and medical tools made from plant material, respectively (Okafor, 2018).

Hard Market to Break

The two biggest obstacles for bioplastics to overcome in the medical field are the reliance that hospitals have on single-use plastics and their higher cost. As of now, single-use plastics are considered the gold standard for safe and clean medical care. The American Chemistry Council has even gone to say that plastic is the ideal medical material, “Single-use plastics are the cleanest, most efficient way, to facilitate health and hygiene in hospitals” (Kagonma et al., 2012, p.1) This creates a situation where bioplastics will need to perform as well as, if not better than, petroleum-based counterparts to be considered as a viable replacement. The other problem with bioplastics is their relative cost compared to traditional plastics. The cheapest bioplastic on the market today is PLA and it's almost eight times more expensive than the next petroleum-based product (Choudhary, 2020). The current use of plastics in medicine and the cost of bioplastics will be the biggest challenges in implementing them as common practice. However, the bioplastics industry is projected to be worth 6.8 billion dollars by 2025 (Naranic et al., 2020). This shows that there is a market for it and it's growing too.

STS Theory

This problem is rooted deep in society and will require social-technical analysis to figure out why single-use plastics came into being, the complex network that support the technology, and the challenges ahead for alternative solutions. First, defining sustainability will help showcase the societal factors needed to drive the success of this product and how sustainability can mean many different things to different people. Interviews with experts will show how broadly the definition can be applied and will help hone in on what sustainability needs to mean in the context of this project. Looking at other countries efforts to implement plastic recycling programs will offer insights into how this problem is being mitigated in different ways and the steps that are taken. These then will be compared back to the US to reveal next steps.

Sustainability

Sustainability is a buzzword in almost every industry sector and has a very ambiguous meaning depending on the context. However, it elicits a positive response and has a normative connotation, meaning that people find sustainability to be a desirable facet even if they don't necessarily know why something is sustainable (Bos et al., 2014). For the medical device industry, what society deems sustainable or necessary will be key in creating a product that is holistically sustainable. Sustainability must consider the wider picture including the energy required to manufacture the raw materials, the impact of different logistical demands, and disposal (Mathews et al., 2020). Just because the material can degrade doesn't necessarily make it sustainable. The focus of the project will be to create a product that is balanced in all areas. Sustainability has also come to include this idea of balance between three areas of performance: economic, environmental, and societal, which is known as the "triple bottom line" (Carter & Rogers, 2008) If the product is environmentally and socially viable but not appealing from an economic standpoint, the product will fail. Only when a solution can be competitive in all three areas will a product become sustainable. Any sustainable product isn't going to be industry breaking overnight; it will need to gather steam from the people who are using the device directly and reflect their values. Another facet of the sustainability question is where the push is coming from and why. Most sustainability initiatives were based upon staff member values, not upon organizational ones (Rodriguez, 2020). These early trends of people wanting to change will hopefully lead to top-down action. This meshes well with the idea that sustainable measures must not only minimize negative effects, but also encourage community involvement (Gibson, 2006). Even with a successful implementation and involvement of the community, Gibson highlights the fact that sustainability is an open-ended process and there are always more improvements to be made (2006).

Interactive Sociotechnical Analysis

Harrison writes on how Interactive Sociotechnical Analysis (ISTA) can be used to evaluate a new system when it gets put into place and the unintended consequences that could follow (2007). These unintended consequences could lead to implementation failure and undermine what the system was trying to accomplish. ISTA focuses on the emergent and recursive interactions a system has with existing social systems, technologies, and physical environments (Harrison, 2007). It's impossible to foresee all of the outcomes when a new system is introduced; however, ISTA can be used to track and identify problems and help solve them before failure occurs. This Interactive Sociotechnical Analysis would be an excellent metric to apply to the new system of introducing bioplastics to hospitals. The ISTA uses categories to stimulate thoughts on how a new system will be received. The introduction of bioplastics will have effects on societal, technical, and physical systems. This analysis will be useful to uncover unintended consequences in implementation and address the challenges in solving this problem. Reiteration of ISTA would continue with the implementation of the bioplastic. This would allow analysis of the unfolding consequences as the product was fine-tuned. Additionally, the use of ISTA would allow insight on how bioplastics might evolve over time or into response to a deign change brought upon by the producer.

Research Question and Methods

Can the introduction of biodegradable bioplastics into the medical industry provide US hospitals with materials that meet medical standards and are economically viable while not *contributing to the growing plastic crisis?* The research question is important because hospitals play a part in the compounding environmental crisis. The decomposition of medical plastics leads to carcinogens being released into the air, water, and soil. With the use of bioplastics, there exists a solution that can still provide the mechanical and sterile properties that medical devices need in order to be effective but won't contribute to pollution. However, this is easier said than done. The societal factors of why single-use plastics are used pose a big barrier to this project's success. There will need to be an in-depth analysis in order to figure out the validity of this project. To accomplish this, interviews will be carried out in order to explore the problem space more. Brigette Torrise and Sonali Luthar, both University of Virginia (UVA) medical students and sustainability initiative members, have been interviewed and their responses were used to answer the research question. The questions that were asked are located in Table 1.

INTERVIEW QUESTIONS
1. What does sustainability mean to you, what (of the triple bottom line) sustainability aspect is most important?
2. Have you seen any program like this?
3. What is the viability of a project like this?
4. What would you think would help / be the biggest road block?
5. Is immediate human health worth environmental damage down the road?
6. Where do you see the biggest areas of waste occurring in the medical sector / what single-use plastic item would be most easily be receptible for this type of switch?

Table 1: Interview Questions

The questions in Table 1 will be used to further develop knowledge about the success of bioplastics in hospitals. The first question will be used to find what aspects of sustainability are most important to the success of the project. The three aspects of sustainability: economic, environmental, and societal as defined by the “triple bottom line” will be ranked by the interviewees from 1 being most important and 3 being least important. These results will be recoded and combined to find the most important aspect of sustainability to focus on for the success of the project. Questions 2-4 will be used to explore the validity and possible pitfalls to the project. Question 5 investigates social and moral intersectionality of ethics between short-term human health versus long-term environmental preservation. The last question serves as future research and exploration into alternative avenues for bioplastics. These questions were also edited depending on the interviewee in order to ask better suited questions based on their field of interest. For example, Sonali, a member of UVA’s Materials Working Group was asked to see if any of her programs could be adapted to be used for bioplastic implementation and what that transformation would require.

As of right now, the economic factors of creating a new product for a well-defined area won’t allow overnight success. The topic will be analyzed by looking at the societal factors for change and sustainability and where successful recycling programs have been used before. The recycling programs from New Zealand and Australia will serve as a comparison to US programs. Data from US hospitals, including plastic usage in hospitals, the existence of plastic recycling programs and their success will be used to find areas where the US can improve. Finally, ISTA analysis of the interactions between humans and technology will be used to see how the switch to biodegradable plastics will affect other actors. This data will be interpreted to bridge together large areas of study into a cohesive argument about healthcare and sustainability. ISTA then can be used to explore the failures of certain actors and the effect it has on a successful bioplastic launch.

Results

In an ideal world, bioplastics could provide an alternative to medical grade single-use plastics. However, the implementation of bioplastics into the US healthcare has no real incentive or systems in place to make the switch. In part due to the complexity of hospital systems, duty of healthcare providers, economic factors and the overall societal perspective on recycling. Interviews with members of the University of Virginia hospital system uncovered many unintended consequences of bioplastic implementation. With the help of ISTA these unintended consequences were sorted into categories that made it clear what societal and technological systems would be affected. The interviews also opened up discussion on other ways that hospital waste could be reduced

Interview Discovery and ISTA Analysis

During interviews wide scale changes to both physical and societal systems and the crosstalk needed between hospitals, recycling programs and the product provider posed obstacles to the success of medical plastic recycling. This includes factors like hospital culture not being susceptible to new protocol changes and the need for waste infrastructure overhaul. Chiefly, the new infrastructure needed for correct collection and sorting would be immense (Luthar, 2021). New protocols on how to sort and dispose of bioplastics, the physical bins, removal and eventually disposal would all need to be correctly implemented in order for success of the project (Luthar, 2021). This ties into the question of, who is willing to make change? All of these actors need to be on the same page in order for this to work. If one of these systems breaks down the likelihood of success shrinks. The product provider, hospital executive board, hospital staff and sustainability initiative would all have to have clear communication to make sure the correct waste ends up in the right place (Torrise, 2021). Hospital workers will also be unlikely to take the time to learn a whole new disposal protocol due to hospitals already being very busy places (Luthar, 2021). Others won't be willing to make the switch due to the fact that the current system works so well. If the current system isn't broken the emergent technology has no problem to solve (Luthar, 2021). Contamination is also still a problem, washing of all post-use bioplastics will need to be carried out in order to be accepted to a recycling facility. This requires more money than just throwing the plastic away (Torrise, 2021).

Additionally, the culture in hospital system favors just throwing things away even if they don't necessarily need to be disposed. Examples include scraping unopened equipment in an operating room in the case of a canceled procedure (Torrise, 2021). As well as medical equipment that comes in a pack due to different sizes, like needle gages, getting scraped if only one is used in the pack (Torrise, 2021). These types of protocols favor throwing perfectly good equipment away in order to stop contamination. However, most of the time the equipment is still perfectly sterile. One other area to consider for single-use plastics items, like gloves, is that healthcare professionals have personal preferences like, what color their gloves are (Torrise, 2021). They don't necessarily care that the gloves are better quality, the right gloves for the job or biodegradable, they just want their favorite color. This shows that in most cases, sustainability aspects of an emergent technology can't be the main selling point. There has to be something novel or time-saving in order for people to take interest. The fact that the product can biodegrade is a secondary perk to whatever novel solution your product provides. Therefore, a biodegradable syringe would have to do something better than the plastic one as well as be biodegradable.

These single-use plastics are also abundant and sometimes interchangeable. If a new product comes along it might not be deemed important enough to make any real impact for the amount of risk that could possibly be introduced to the hospital (Torrise, 2021).

To further investigate the interactions between the implementation of bioplastics into the hospital realm ISTA analysis was performed to reveal unintended consequences and identify where the implementation would run into problems. ISTA is good at identifying system level barriers that would hinder the success of a technology. To do this the framework looks at the subcomponents of sociotechnical system that act as major sources of unintended consequences (Harrison, 2007). The five interaction types that were analyzed all look at how bioplastic implementation can affect the existing social and physical systems, and then how these systems can mediate back onto the introduction of bioplastic implementation. The information from the interviews was gathered and presented in ISTA format in Table 2.

ISTA Type	Unintended Consequence
1. New bioplastics protocol changes social system	• Creates more work for healthcare professionals in an already stressful environment.[1] • New training and protocol needed to successfully implement; this requires the investment of more time and resources.[1]
2. Technical and physical infrastructure mediate bioplastic implementation	• The use of single-use plastics does such a good job both providing a sterile and cheap device.[2] • The creation of new physical collection bins or sites slows down the collection of other waste.[1]
3. Social systems mediate bioplastic implementation	• Staff will incorrectly place waste in appropriate bin leading to the whole batch needing to be trashed, either due to contamination or lack of training.[1] • The willingness to recycle isn't present in the realm of healthcare due to its extra time and effort needed.[2] • Staff won't want to sacrifice human health for environmental preservation.[2] • Hospital executives won't deem the project economically viable or necessary.[2]
4. Bioplastic implementation changes social system	• Need for system-wide infrastructure changes. The provider, hospital and recycling company would all have to agree.[1] • The development of new recycling bins clutters already busy hospitals. [1] • New staff protocol takes healthcare professionals from more important areas.[1]
5. Bioplastic implementation interactions give rise to bioplastic redesign	• As the system evolves, the demand for more products can put strain on supply lines.[2] • Failure of bioplastics would lead to reverting back to plastic. This would cause massive losses in infrastructure that is now obsolete.[1] • Increased upfront costs lead to budget cuts in other sectors.[2]

Table 2: ISTA Analysis

[1] Luthar, S. (2021, March 16). Personal communication [Zoom Interview]

[2] Torrise, B. (2021, March, 19). Personal communication [Zoom Interview]

After ISTA analysis, the mounting problems against the implantations of bioplastics in hospitals becomes more pronounced. The need for entire new training programs, system-wide recycling infrastructure, and healthcare workers not willing to sacrifice time or safety for new emergent technology hinders the ability for this technology to be implemented. The interviewees were also asked what part of the "triple bottom line" they felt was the most important to the success of bioplastics in hospitals. Out of economic, social and environmentally sustainability both replied that economic sustainability as the most important factor when implementing this type of technology. This is mostly due to the cheap and interchangeable nature of small plastic medical devices. These devices are seen as expendable and cost is really the only thing that a hospital would worry about (Luthar, 2021). The high upfront cost to equip hospitals with the infrastructure needed to recycle these plastics and the high unit price keep bioplastics from being economically sustainable. This then violates the "triple bottom line" and can't be seen as a truly sustainable success.

With this in mind, there are ways that hospitals can become more sustainable. Instead of revamping an entire system and introducing a new product, there are smaller actions that could be done to curb medical waste. Better communication between hospital staff would stop unnecessary waste from occurring in the first place (Torrise, 2021). Smarter and smaller packaging can also be used for items that are needed together (Torrise, 2021). Focuses into other hospital areas like cafeterias might also be easier to implement than the operating room.

Discussion

The goal of the project was to create a plastic that can be mechanically viable and able to degrade back into the environment without releasing carcinogens. This would make the healthcare industry as a whole more sustainable. The other repercussions of this project would be the training of medical staff on how to properly dispose of the bioplastics. This would require new training and awareness on how to sort medical plastic waste more effectively. This hopefully will lead to a new generation of greener thinking and spill over into other areas. Healthcare is a necessity for today's world, but it doesn't have to pollute the planet at the same time. Bioplastics would be the first step in a new era of sustainable health practices. However there exists roadblocks in the way of success and a refocus of bioplastics into other areas might prove more effective.

Global Comparison

The idea of new training and recycling awareness has already begun in other countries and can serve as a comparison to US hospitals. This would ideally serve as proof of concept and a template for the US to follow. However, the US is so far behind and geographically large that nationwide adoption is unlikely (Sparrow, 2019). One model for the US to follow includes an initiative that was started in Australia in 2009 and now contains over 140 hospitals in Australia and New Zealand (Sparrow, 2019). The program provides specialized segregated plastic recycling bins for different types of medical plastics and training to medical staff on how to identify and categorize waste appropriately (Sparrow, 2019). This allows medical plastics, chiefly PVC, to be sorted into correct categories in order to be recycled and not contribute to pollution. This program also works directly with medical device companies, encouraging the design of more recycling friendly products. Australia and New Zealand credit the success of the program to the predisposition that their respective populations have towards recycling and environmentalism (Sparrow, 2019). The hospitals are staffed by people who are already more inclined to recycling due to the position their society takes on the issue. However, in the US, there is no nationwide policy on recycling in general, let alone policy on medical recycling (US EPA, 2015). Coupled with the fact that the biggest success of recycling programs comes from very active grass roots networks and not top down or producer marked forces hinders the participation of hospitals into bioplastic implementation (Raysavy, 2020). This ties well with the idea of technical style. All the countries involved have healthcare systems, but the willingness of Australia and New Zealand to push for more sustainable practices from a grass roots level allows for easier transition into medical waste programs than the US. This societal outlook will need to be instilled in the US before the success of bioplastics and other hospital recycling programs. The old school medical values will need to be persuaded by outside change before success of bioplastics can occur.

Future Research and Advancement of Engineering Knowledge

Limitations of this project include a lack of research into the actual systems that would take care of the recycling. There are entire pathways that could be investigated outside of just the hospitals part in bioplastic implementation. Interviews with people in US based medical recycling companies, providers of current sustainable medical technologies, and 3rd party sustainability initiatives would all be good avenues for future research. This would allow a more comprehensive look into the entire life cycle of bioplastics from producer to hospital to recycling. Future research into more sustainable hospital practices or technologies could also prove useful in mitigating waste. An example includes the investigation on emergent virtual reality technology that would allow doctors to practice procedures virtually without creating any waste.

This project would benefit by changing the industry that was chosen for bioplastic implementation. For all of the reasons stated above, the rapid transition into bioplastics into hospitals might be too idealistic. However, this doesn’t mean this type of analysis and implementation can’t work in a different sector in the future. Places where human health isn’t at risk and there is more room for funding, chiefly from the consumer, would be better suited for a sustainable plastic transition.

This research advances engineering practice by showcasing how to correctly identify markets that can be better suited for emergent sustainable technologies. This research also shows the importance of understanding what it means to actually be sustainable and how success in one area is meaningless without success across all three of the “triple bottom line”. The ability to analyze unintended consequences helps engineers identify failures before they occur and in turn save investors from wasting time and money if the idea will fail.

Conclusion

Overall, the problem of single-use plastics and their negative effect on the environment is a problem that is deeply rooted in the medical industry and doesn’t have an immediate need to change due to the success of petroleum plastics. The negative outcomes of plastic pollution haven’t outweighed the need for single-use plastics; however, irreversible damage will continue to compound if nothing is done. The significance of this research shows how hard it is to be successful in all three areas of sustainability and the amount of system wide change needed in order to implement a product like this. This project has the potential to not only provide a mechanical and medically viable replacement, but also to change the culture around single-use plastics and take a hard look at why US hospitals produce as much waste as they do and the societal factors behind it. This opens up future work to looking at smaller scale adoption of this project in a system that is both smaller and more willing. The UVA hospital system is more well suited to be able to adopt one bioplastic product initiative rather than all single-use products. They also have the sustainability initiative and infrastructure to pull it off. Pending the success of the product, UVA could then be a model for adaption at another hospital. Growth will be slow and require grassroots movement, not country wide system change. The success and takeaway of this project come in the form of hopefully providing a stencil for other sustainable practices to be implemented elsewhere in society. Food service and retail, where there are less system constraints and more consumer capital, would be more susceptible to bioplastic success. The research also shows that sustainability is a systems-based problem and therefore will need system wide changes to be able to provide medical care and preserve the earth at the same time.

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