Designing and Applying an Alginate-Based Biopolymer for Adhesive Bandages

Grant Proposal

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Abstract

The need for an environmentally friendly, effective, and easy-to-use bandage is vital now more than ever. With the increase in climate change as global temperatures rise, pollution's irreversible effects are being taken lightly. Plastic pollution, especially which accounts for most of these pollutants released into the atmosphere, is mostly due to the use of polyethylene products. While cheap and have a surplus of them, products made from the material take hundreds of years to break down, hundreds of years that planet Earth does not have. Some current knowledge gaps in this field of biomedical applications of materials such as alginate for wound dressings include ideal concentrations for peak efficiency, how to increase the mechanical properties with the addition of substances like nanoparticles, as well as how to effectively test out these wound dressings on non-humans. Considering all these knowledge gaps, the researchable question identified in this field was how to create an alginate-based biopolymer hydrogel bandage that is effective in reducing bacterial infection, but also biodegradable and can withhold the stress of a plastic bandage.

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Around 2300 tons of bandages are either burned or thrown away in U.S. hospitals each year, and people say that these single-use plastic bandages made of polyethylene can't be replaced with reusable ones. Polyethylene is a commonly produced plastic and even though they are durable, versatile, and cost-effective, they have a detrimental impact on the environment. There is a plethora of products used in everyday life made from it which even further contributes to the increase of plastic waste in the environment. Incineration is waste treatment through burning, also known as thermal treatment. Often disposed of by landfill or incineration, the plastic itself is not biodegradable and its toxic remains eventually end up in aquatic environments, which can cause entanglement with marine animals (Yao et al., 2022). Common drug store bandages also present with various issues such as leading to bacterial infection due to an overly moist environment for the wound, as well as chemical contamination from the disposal of the product. Not only does this improper disposal of the bandages contaminate the soil and water, but the waste leaves behind microplastic particles that harm the surrounding ecosystems.

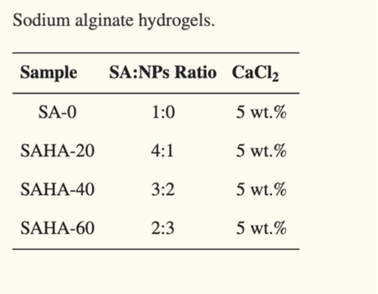
Various materials have been experimented with over the years to remediate this issue on a larger scale in terms of wound dressings, the most common of these materials being bamboo and alginate. Alginate is a naturally occurring anionic polymer that is most often derived from brown algae through a process of extraction. In this process, the algae are stirred in a solution with sodium carbonate until dissolved as sodium alginate, and then through dilution and filtration, mixed with calcium chloride to make fibers which can then be transformed into a biopolymer using a screw press to remove the excess water (Kumar et al., 2021). Following this, the biopolymer can be molded, and the alginate-based biopolymer can be used to create a hydrogel. Hydrogels are effective for various mild wound surfaces in which a cooling effect is emitted on the skin in addition to absorbing the moisture to prevent bacterial infection. As indicated by the name, hydrogels can hold large amounts of water without dissolving and can be obtained by radiation technique in several ways including irradiation of solid polymer, monomer, or aqueous solution of polymer.

Although alginate is commonly used in the pharmaceutical aspect and generally in the healthcare field as a wound dressing, the true extent of it as a bandage is unknown. The overall effectiveness in comparison to traditional bandages has not been explored thoroughly in the past, as well as the integration of this biomaterial as a wound dressing is beyond the scope of a gauze-like material (Aderibigbe & Buyana, 2018). With the recent advances in biopolymer-based hydrogels in terms of the immune response and cellular activity, it has been found that the addition of nanomaterials can mimic the environment to test these materials (Patel et al., 2023). Not only does this indicate that the hydrogels can be cross-linked physically or chemically depending on their structure, but even further expands the horizon for the abilities of biopolymer-based hydrogels. However, an in-depth understanding of the biomedical applications of these hydrogels is significantly unknown with this material which leaves room for secondary exploration.

Current Developments

Currently, there are a variety of wound care products such as foam, gauze, and hydrocolloid dressings, however only a select few of them are environmentally friendly. While some of these said products are made with alginate, there comes an increased cost and decreased level of effectiveness. Alginate bandages are not the standard, meaning they are more expensive, leading individuals to purchase traditional bandages. Additionally, these traditional bandages often lose adhesivity quickly and result in an unsuccessful product overall (Fumarola et al., 2020). Additionally, as seen in Table 1, the addition of the nanoparticle hydroxyapatite (Sánchez-Fernández et al., 2021) has been tested with alginate to improve mechanical properties, and while it did show improvement, the potential for nanoparticle additions is far vaster.

Table 1: The sodium alginate to hydroxyapatite ratio in a study testing the mechanical properties of different concentrations of nanoparticles when cross-linked with calcium chloride.



Sodium alginate hydrogels.

Sample	SA:NPs Ratio	$CaCl_2$
SA-0	1:0	5 wt.%
SAHA-20	4:1	5 wt.%
SAHA-40	3:2	5 wt.%
SAHA-60	2:3	5 wt.%

Risk/Safety Concerns

One potential safety concern that may arise from this procedure is getting calcium chloride on one's hand as it can irritate the skin and lead to extreme dryness. This may occur during the process of cross-linking when each alginate concentration is combined with a certain volume of calcium chloride and then let sit overnight for peak results. This hazard will be counteracted by always keeping gloves on the experimenter’s hands, as well as using safety goggles to reduce the chances of getting the calcium chloride or alginate from entering one's eyes. Additionally, using the freeze dryer may pose on the more dangerous side due to it involving extremely cold surfaces, however, undergoing the correct protocol and safety procedures as well as using gloves to reduce the risk of contamination for the samples will prove effective in its safe usage.

Global Need

With the rate of global warming on the rise, these primarily polyethylene plastics are endangering the hope of keeping the global temperature annual increase under 1.5 degrees Celsius (Ford et al., 2022). Therefore, there is a demand to create a bandage that adheres more effectively to wounds than current bandages and is biodegradable which contributes less to plastic pollution such as an alginate-based bandage.

Section II: Specific Aims

This proposal's objective is to reiterate the pressing issues that plastic pollution presents to the scientific community. The aim is to make an environmentally friendly bandage, lessening the millions of tons of burned plastic each year globally. The hope is that society will take action to fix this issue. The central hypothesis is that if there is an addition of biodegradable nanoparticles such as gelatin to calcium chloride cross-linked alginate, then this will create a biocompatible and biodegradable biopolymer hydrogel that can be applied to a bandage. The rationale is that the addition of the nanoparticle hydroxyapatite (Sánchez-Fernández et al., 2021) has already proven to be effective in improving the mechanical properties of alginate hydrogels, so experimenting with other biocompatible nanoparticles should even further increase these properties, therefore its usage. The work proposed here will not only change the biomedical field but also the world's global warming rates.

Specific Aim 1: Test out and create around seven iterations of alginate hydrogels with varying alginate concentrations when cross-linked with calcium chloride to perform mechanical tests.

Specific Aim 2: Perform mechanical tests such as simulating a monotonic compression test where each hydrogel will be measured for its overall strain due to differing stresses applied.

Specific Aim 3: Once the top three concentrations are determined, remake hydrogel this time using a mold to get into an ideal bandage shape, and test out applying the material to gauze.

The expected outcome of this work is to find the prime concentration of alginate when cross-linked, that will prove to be the strongest and can withhold increasing amounts of pressure while remaining intact and with little deformation present.

Section III: Project Goals and Methodology

Relevance/Significance

Global warming due to pollution, specifically plastic pollution has been an ever-present issue in today's world. From the multitude of plastic products that humans use to their common misplacement when disposing of the materials, millions of tons are burned. This burnt plastic ends up in marine waters, and even on the side of the road (Iroegbu et al., 2021). Unable to degrade for thousands of years, the plastic pollution especially just continues to pile up, and will one day completely wreak havoc on the planet. To remediate a section of this plastic waste, alginate-based bandages are crucial to reducing bandage waste. Not only will this bandage be biodegradable but will aid in reducing the detrimentally elevated increase in global temperature each year.

Innovation

Testing a variety of biodegradable and biocompatible nanoparticles such as gelatin would be an example of innovation in terms of this project, as it has not been done before. While the addition of nanoparticles like hydroxyapatite has been added to alginate hydrogels to improve their overall mechanical properties, there is still a large knowledge gap in the addition of nanoparticles as well as room for improvement in this field. In other words, this means that the exact effects of adding various nanoparticles to alginate are mainly unknown as this is not a common test that is conducted.

Methodology

Creating and testing out the different concentrations of alginate will help determine the most ideal one, in which it can take a significant amount of stress without deforming at a large enough rate for rupture. Using calcium chloride, alginate powder, and potentially two flat metal baking pans to simulate a monotonic compression test, these materials will allow for the collection of data on the superlative alginate concentration.

Specific ***Aim #1:***

Determine the ideal concentration of alginate that will prove to hold the highest pressure without rupturing when mechanical tests are conducted on it, potentially even going back to its original form when the pressure is taken off.

Justification and Feasibility

The procedure for this project begins with cross-linking the alginate and calcium chloride which will produce a viscous solution. Using a magnetic stirrer to mix the different alginate concentrations in a beaker with distilled water will aid in making a fully dissolved mixture. This is crucial in making the ideal solution, as each concentration will be necessary for determining the one with the best mechanical properties for specific aim two.

Expected Outcomes

The overall outcome of this aim is to create seven iterations of alginate concentrations that are cross-linked with calcium chloride. This knowledge will be used for the implementation of these hydrogels to conduct compression tests.

Potential Pitfalls and Alternative Strategies

We expect that some concentrations of the cross-linked alginate will not form hydrogels in the ideal shape, however creating a circular or rectangular mold from materials like a plastic water bottle can remedy this. In addition, it is expected that some concentrations will look the same and may be mixed up, however, it is a necessity to correctly label them and be extremely careful when draining the calcium chloride so that the hydrogel does not fall out.

Specific Aim #2:

Determine the overall strain due to the stress applied that each alginate hydrogel can endure. The objective is to perform mechanical tests such as a monotonic compression test and ultimate compressive tests to measure the deformation each hydrogel can take without rupturing. The rationale for this approach is based on basic mechanical biopolymer tests that are often conducted, and these tests will help form a stress-strain curve.

Justification/Feasibility

Using this method of mechanical testing will make clear which alginate concentration for the hydrogels was most effective, meaning the one that proved to have the highest mechanical properties as shown in Table 1. This is crucial in determining at this stage in the project as the hydrogel that moves on to a bandage in specific aim three must not only be durable but also have a high elasticity as shown in a stress-strain curve as seen in Table 2.

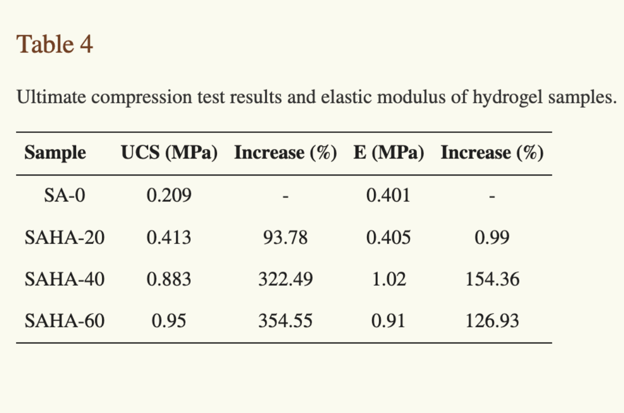


Table 4

Ultimate compression test results and elastic modulus of hydrogel samples.

Sample	UCS (MPa)	Increase (%)	E (MPa)	Increase (%)
SA-0	0.209	-	0.401	-
SAHA-20	0.413	93.78	0.405	0.99
SAHA-40	0.883	322.49	1.02	154.36
SAHA-60	0.95	354.55	0.91	126.93

Table 1: The results of an ultimate compression test and elastic modulus of hydrogel samples with different concentrations of hydroxyapatite nanoparticles are shown (Sánchez-Fernández et al., 2021). The compressive strength test measures the strength needed to rupture materials, with ones like plastic having a high score. This means that the test measures how much force a material can handle before failing. "E" which represents Young's Modulus measures the elasticity of a material and is calculated by solving tensile stress/ tensile strain.

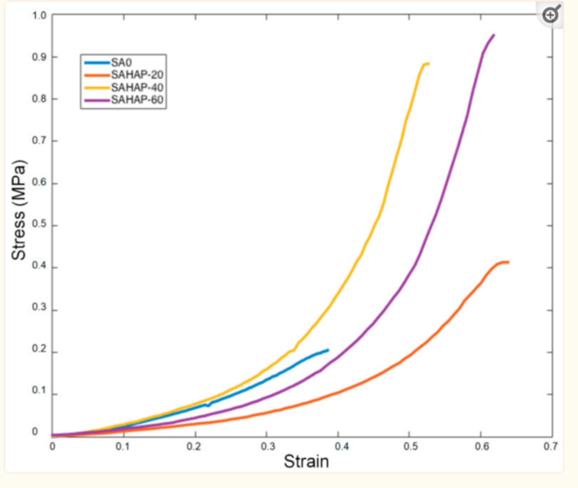


Table 2: Shows a stress-strain curve in a test on the effects on the mechanical properties of alginate with the addition of hydroxyapatite (Sánchez-Fernández et al., 2021). This curve shows the material's behavior when under extreme force and focuses on the part of the graph where each line is linear since stress is linearly proportional to strain. With the slope being Young's Modulus, this graph also shows the elasticity of each concentration.

Expected Outcomes

The overall outcome of this aim is to analyze the mechanical properties of each alginate concentration, finding which ones could handle larger amounts of stress without rupturing and failing. This knowledge will be used for aim three where the top two or three concentrations will be placed in a freeze dryer and applied to a bandage.

Potential Pitfalls/Alternative Strategies

We expect that the value for the ultimate compressive and monotonic will be quite small, however in comparison to the control of just pure alginate, there will be an increase in its maximum applied force. In addition, the value for Young's modulus will be on the lower side due to it being an elastic-like material, however, its elasticity may be improved by testing out the addition of nanoparticles such as silica and gelatin.

Specific Aim #3:

Determine the top three concentrations of cross-linked alginate and use a mold to shape and place them in a freeze dryer. With the objective being to create a porous scaffold and use the freeze dryer to extend its shelf life, the rationale is to apply this hydrogel to a gauze-like material in one iteration.

Justification/Feasibility

Using compression molding to configure the hydrogel in a rectangular shape. From there the hydrogel will be placed in a freeze dryer to undergo sublimation and remove excess water to extend shelf life (Sornkamnerd et al., 2017). Once this cycle is completed, either the hydrogel itself or one soaked in a gauze-like material that then passes through the freeze dryer will be added to a bandage. This bandage will likely be a bamboo one that is biodegradable and there is a surplus of. From there the bandage will need to undergo several tests including one to test its tensile strength, and one on a mock wound to inspect bacterial infection and wound fluid absorption.

Expected Outcomes

The overall outcome of this aim is to discover a way to preserve the hydrogel and apply it to a bandage that is adhesive but not made of a material that is not environmentally friendly. This knowledge will be used to determine what type of wounds these bandages will be able to be used on, as well as further developments that need to be made.

Potential Pitfalls/Alternative Strategies

We expect that creating an adhesive bandage to apply this hydrogel will be difficult, as well as creating the mock wound to observe for wound humidity and bacterial infection.

However, with additional research and an even deeper understanding of the chemistry behind alginates biomedical uses for wound healing, this step in the process is achievable.

Section IIII: Resources/Equipment

The major parts of this project include determining the ideal concentration of alginate to use and finding one that will result in a relatively high tensile strength when cross-linked with calcium chloride. Molding the determined hydrogel is also important in creating a favorable bandage shape material to apply to the bandage once it has gone through the freeze dryer to create a porous scaffold. A porous scaffold is used most for tissue engineering and will aid in the diffusion and proliferation of test substances like methylene blue when undergoing testing. Then finding a way to take this hydrogel and apply it to a bandage as well as creating a mock wound to observe for bacterial infection and wound moisture will aid in determining the effectiveness of the designed bandage. The independent variable is the calcium chloride content, while the dependent variable is the alginate concentration being cross-linked with the calcium chloride. The controls in this experiment would be a baseline two percent alginate concentrated biopolymer hydrogel which will be used as a comparison for each iteration. The goal is to test about five to eight iterations of alginate concentrations to determine the ideal one. The materials required include alginate, calcium chloride, a mold, a freeze dryer, a pipette, a petri dish, a syringe, and any additional materials required to make the bandage with the hydrogel as well as the mock wound.

Data Analysis

During the tensile strength test, we'll check how the bandage reacts when specific forces are applied. We want to see if it breaks under the force measured by the load cell. The load cell is what converts this force of compression into a signal that can be measured in millivolts per Volt. Since various concentrations will be tested and potentially a variety of sizes, generalizing this measurement will be done by dividing the force applied by the initial cross-sectional area. Then dividing the amount, it moves by the initial length of the material, a stress-strain response can be analyzed. This response will look for the relationship between stress and strain in the deformation of the material.

Using stress-strain curves, measuring Young's Modulus, as well as compression testing, the increase in mechanical properties will be measured. Optimal outcomes of these tests would include a relatively higher force being able to be applied to the hydrogel without rupturing in comparison to the two percent alginate concentration, while an overall low Young's Modulus value would be ideal due to this indicating a higher elasticity.

Section V: Ethical Considerations

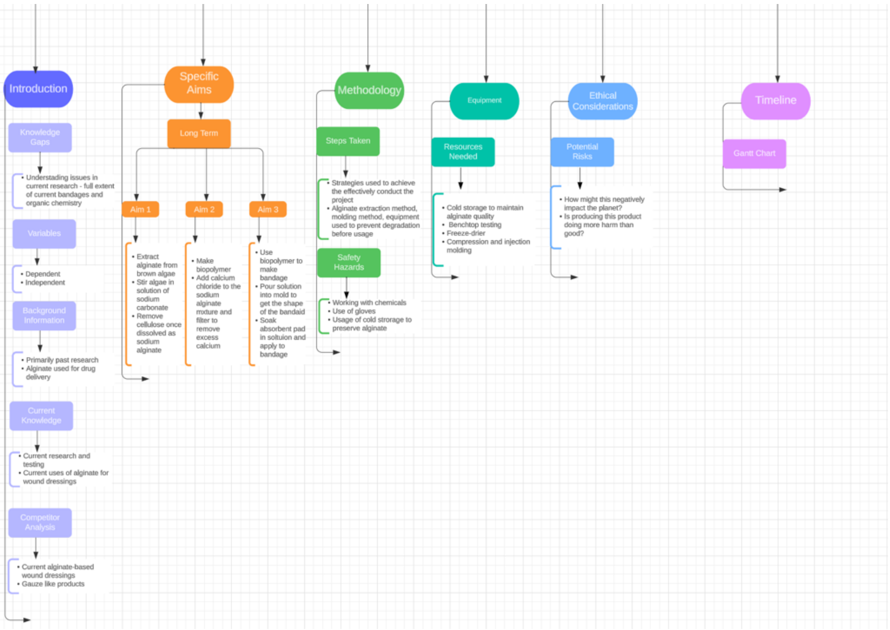
Some ethical considerations that have been apparent within this project so far have been the potentially harmful environmental impact that creating this product will have, as well as any other factors in its creation that will ultimately do more harm than good. In other words, the production of any material is bound to hurt the environment due to the fossil fuels that the factory where it is produced emits, however, the question being considered here is will the benefits of this bandage outweigh any emissions it may contribute to the existing pollution issue.

Section VI: Timeline

https://app.teamgantt.com/projects/gantt?ids=3691113

Section VIII: Appendix

Appendix 1: Systems Map of Project



This system map outlines the basic steps of this project, entailing all the major steps, methods, and technology required.

Section VIII: References

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