Project Proposal

Project Title: Designing and Applying an Alginate-Based Biopolymer Hydrogel for Adhesive Bandages
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Project Description:

The overall aim of this project is to design an alginate-based biopolymer hydrogel to replace the absorbent pad on environmentally friendly adhesive bandages. Within the scope of this project, various concentrations of alginate will be tested with two different nanoparticles of differing concentration, to first analyze the structural integrity of each solution when cross-linked with calcium chloride. The addition of these nanoparticles is in order to address the current low mechanical properties of alginate wound dressings, and will be observed for the most effective one. Using freeze drying and a universal strength testing machine, the hydrogel will be dried via sublimation and tested for compressive strength. When the cross-linked alginate is submerged in the calcium chloride, it is expected that its overall durability will increase as well as have an improved compressive strength. In addition to this, this hydrogel being alginate-based will allow it to degrade in a timely fashion as well as increase the overall wound recovery rate.

Background:

How can the materials that typical drug store bandage abosrbent pads are composed of, be improved to allow for enhanced wound healing with rapid recovery rates, as well as be biodegradable? If nanoparticles added to alginate are tested as a potential replacement for polyethylene in bandages, then the overall biodegradability, wound healing process, and mechanical properties will improve drastically due to it having the ability to absorb wound fluid, degrade easily into the environment, and withhold its structure while being stretched.

General Relevance

With an estimated 2300 tons of bandaids burned in hospitals or thrown in landfills each year in the U.S., these polyethylene single-use plastics are claimed to not be able to be replaced by a reusable item. Polyethylene is commonly produced plastic that while they are durable, versatile, and cost-effective, has a detrimental impact on the environment. As this is one of the most common plastics, 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 the material, also known as thermal treatment. Often disposed of by landfill or incineration, the plastic itself is not biodegradable and its toxic remains especially in aquatic habitats 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 also leaves behind microplastic particles that harm the surrounding ecosystems. 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. While alginate is used for gauze like materials in the current market, its overall mechanical properties are significantly low. In addition to enhance these low mechanical properties, the addition of a nanoparticles such as hydroxyapatite (Sánchez-Fernández et al., 2021) has been tested. While proven to increase the durability and weight threshold of the material, there is a wide space for improvement.

Knowledge Gaps

Although alginate is commonly used in the pharmaceutical aspect and just generally in the healthcare field as a wound dressing, the true extent of it as a bandaid is not fully known. 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 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 is capable of mimicking 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. In addition, a comprehensive understanding of the organic chemistry of alginate and calcium chloride is crucial in understanding why certain reactions occur, such as why the sodium alginate forms a viscous solution when cross-linked with calcium chloride. In addition, nanoparticles additions to alginate hydrogels has not been widely tested, so in addition to the biodegradable nanoparticles of gelatin and silica that are planned to be used, additional ones and determining other nanoparticles that would be most effective would require extensive research.

Competitor Analysis

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 thus meaning they are more expensive, leading individuals to purchase the traditional bandages. Additionally, these traditional bandages often lose adhesivity quickly and result in an unsuccessful product overall (Fumarola et al., 2020).

Researchable Need

Therefore, there is a demand to create a bandage that adheres more effectively to wounds than current bandages, reduces bacterial infection, and will contribute less to plastic pollution such as an alginate-based bandage. Utilizing primarily a freeze drier (Sornkamnerd et al., 2017) to form the biopolymer hydrogel, the ideal concentration of alginate and nanoparticles will be developed to incorporate in the wound dressing, or bandage in this case.

Experimental Design/Research Plan Goals:

The major parts of this project include determining the ideal concentration of alginate to use, determining which nanoparticle enhances its mechanical properties the most, and finding one that will result in a relatively high compressive strength when cross-linked with calcium chloride. Molding the determined hydrogel is also important in creating the favorable bandage shape material in order to apply to the bandage once it has gone through the freeze drier to create a porous scaffold. Then finding a way to take this hydrogel and applying it to a bandage as well as creating a mock wound to observe for recovery rate and wound moisture, which 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 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 five alginate concentrations in order to determine the more ideal one. The materials required include alginate, calcium chloride, freeze-drier, pipette, petri dish, syringe, mechanical stirrer, gelatin, silica, brown planaria, scalpel, well plate, and bamboo bandages. The procedure for this project begins with mixing the alginate solutions, adding the two nanoparticles and their two concentrations to each solution, and then cross-linking each mixture. From there the hydrogel will be placed in a freeze-drier to undergo sublimation and remove excess water to model the absorbent pad of a typical bandage. Once this cycle is completed, the hydrogel will be placed onto an already biodegradable bandage such as a bamboo bandage, where it will replace the absorbent pad. From there the complete bandage will need to undergo several tests including one to test its compressive strength, and then be tested on brown planaria. An incision will be made on the posterior and anterior ends of brown planaria worms that are to be grown and when in the adult stage, in order to test each hydrogel. Once the incisions were made using a scalpel, one hydrogel solution per worm was placed in a well plate using a pipette, and then was observed for time it took to heal and presence of fluid absorption.

Risk/Safety Concerns:

Some potential safety concerns 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 hazard will be counteracted by keeping gloves on the experimenter's hands at all time, 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-drier 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.

Data Analysis:

The data from the compression strength test will look for when certain forces are applied to a sample, the bandage in this situation, if a fracture will occur within the given load cell. The load cell is what converts this force of compression into a signal that can be measured in millivolts per Volt. Due to the fact that 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. From this point, conducting a stress-strain curve will be effective in further analyzing these results, as well as any data analysis that would go into testing the effectiveness of the bandage for wound healing. Imaging software will be used to analyze the recovery rate of each worm for the differing solutions as well. In other words, this effectiveness would entail high wound fluid absorption, recovery time, and overall durability of the hydrogel.

References:

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<u>Timeline:</u> (with action steps identified- sub-deadlines will continue to evolve):

Rough timeline of major phases. As these phases get established, specific tasks under these phases will be defined further.

Background/Deeper Understanding

- Complete emails to labs by November 15
- Read 15 articles by December 5
- Fill in organic chemistry knowledge gap by December 5

Lab Work

- Have lab details and plan completed by November 30
- Begin lab testing by December 1
- Make concentrations of alginate by December 1
- Set up zoom calls with outside professors by December 5
- Solidify materials by November 30
- Finalize testing plan by December 20
- Collect all data by January 20
- Conduct compression tests by January 29
- Design mock bandage by February 5
- Begin testing on brown planaria by January 24
- Make incisions to planaria and place hydrogel on top of wounds by February 6
- Conduct recovery rates using imaging software by February 12