Investigating innovative wound dressings

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Introduction

Wounds are one of the most common types of injury to exist. Nearly everyone has experienced at the very least a small cut once in their lives. But wounds can cause detrimental effects to a person if not properly taken care of. Infections could occur due to the invasion of pathogenic species through the open cut. As such, it is important to explore the ideas and research around wound healing.

In order to make an ideal wound dressing, a number of factors must be considered. Firstly, the dressing needs to be biocompatible to the wound and skin. It must cater to the person's body, factoring in all possible allergies and immune responses that may come about due to the chemicals within the wound dressing. They need to be made for efficiency; the quickest and most effective route to healing the wound. Ideally, they shouldn't leave a scar.

The next topic of study is the physical design and properties. The wound dressing should feel comfortable and be safe for use. This means that factors like flexibility, strength in the bandage (etc.) must be accounted for. They shouldn't cause discomfort like itchiness, and the adhesive should come off smoothly without tearing the surrounding skin.

Finally, the costs need to be assessed. The proposed wound dressing should adhere to the norms of manufacture. This means that majority of the factories around the world should be able to create the product in bulk. The cost of the material must also be evaluated. If it costs too much to make and produce, then the pricing will be greater than the price for current products; this will push away customers.

This report aims to evaluate the advancements of wound dressing technologies. This report will also assess the current methods for wound treatment and how it can be developed in the future for faster healing processes. Henceforth, the chemical and physical properties of the materials will be reviewed. Moreover, the report will examine the potential methods for manufacturing and mass production.

Evolution of design

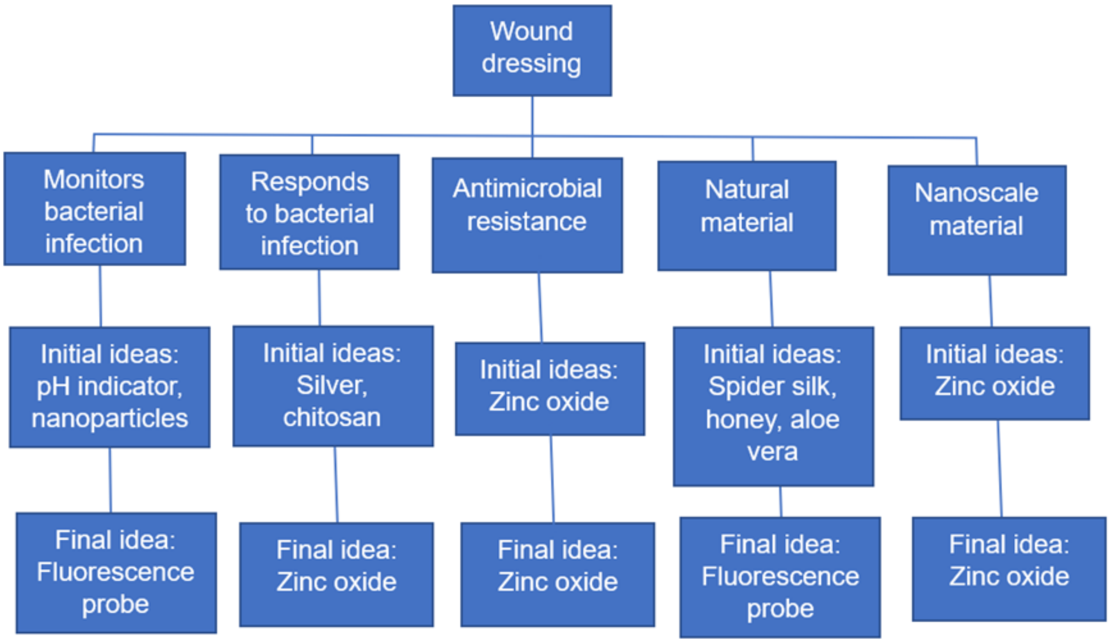

Figure 1 Selection of components

In selecting the components, several requirements had to be met. Firstly, a component had to monitor bacterial infections. This could be shown through a change in colour, change in pH (etc.). In the specified design, a fluorescent probe was chosen for this function. Moreover, it qualified for the need of a natural material.

Further specifications included the desires for components that firstly responded to bacterial infection, a material at nanoscale and finally a material that presented antimicrobial resistance. All of these were met with the use of zinc oxide.

After considering several materials, the use of zinc oxide with a fluorescent probe served to prove the most efficient route to wound treatment. It's a very simple concept with very few ingredients. The idea is to replace the foam of typical plasters with a hydrogel, consisting of the materials mentioned.

Material selection

In this section, the materials chosen for the wound dressing will be explored in detail. The reasoning behind each material will be given and justified.

Zinc oxide

Zinc oxide (ZnO) is known for its many uses, typically in the study of biology. Some of its uses include sunscreen, cosmetics, and pharmaceuticals. It has drawn interest for its antibacterial characteristics, ability to heal wounds, and prospective therapeutic applications in biomedical research and pharmaceutical formulations. For scientists and researchers examining the world of biological sciences, zinc oxide is an attractive material due to its biocompatibility and capacity to interact with biological systems [1]. Understanding the biological functions of zinc oxide in this context opens possibilities to creative developments and hopeful solutions in biotechnology, medicine, and other fields.

Zinc oxide materials are typically used as nanoparticles. It is an inorganic compound that appears as a white powder, insoluble in water. They're used in the rubber industry for its wearproof capabilities and improve the toughness and antiaging of other polymers. Its use in sunscreen and cosmetics provides benefits due to its UV-blocking properties.

Zinc is naturally found in the body; the brain, muscles, bone, skin (etc.). As such, it plays a crucial role in various bodily processes. It should also be noted that zinc is in many foods including red meats, poultry, nuts, and chickpeas [2].

Mechanical properties of zinc oxide

A study integrated zinc oxide with chitosan (Cs) and polyvinyl alcohol (PVA) [3]. In this, the sample with 15 Wt.% of zinc oxide produced the most advantageous results. The tensile strength was measured to be 83.45MPa, and the elastic modulus was $5.34*10^3$MPa. The integration of the additional materials strengthened the zinc oxide, making it more beneficial for use in wound dressings.

Chemical properties of zinc oxide

Zinc oxide has a molecular weight of 81.39. A TEM and SEM analysis exhibited the compound to have spherical and hexagonal particle shape [3]. XRD analysis of zinc oxide, integrated with chitosan and polyvinyl alcohol (Cs/PVA), indicated that the subject had a semi-crystalline nature due to the intermolecular and intramolecular interactions of Cs/PVA wherein hydrogen bonding is present.

A separate study showed that zinc oxide has a density of 5.66 g/cm³ and a melting point of 1975°C [4]. Its high melting point means that it can be applied to patients without concerns of it losing its substance.

There have been several investigations on zinc oxide's antimicrobial activity [5]. Tests for this included disk diffusion, broth dilution, agar dilution, and testing ZnO's toxicity to E. coli. The results for the testing on E. coli growth concluded that the zinc oxide nanoparticles inhibited the bacterial growth. This was shown using UV illumination.

Finally, a study conducted determined the biocompatibility of zinc oxide on the Vero cell line, acquired from kidneys of African green monkeys [6]. In this, a cell culture was prepared and kept in incubation for 24 hours. The results showed greater cell viability in the cultures with zinc oxide. Henceforth, it was concluded that zinc oxide showed characteristics of biocompatibility.

Cost analysis of zinc oxide

The purchase of zinc oxide itself is the main cost element. The price can change depending on the quantity being purchased, the quality and purity of the zinc oxide, and market movements. Zinc oxide is a relatively affordable material and is accessible to everyone worldwide. It costs about £2.50 per 100g [7].

Fluorescent probe

Nitro reductase (NTR) is a prominent enzyme in many bacterial species [8]. They belong to the family of flavin-containing enzymes and can be subcategorised into two divisions: Type I NTRs are oxygen-insensitive, i.e., capable of reduction in the presence of molecular oxygen, and type II NTRs are oxygen-sensitive and only function under extreme hypoxia environment (where oxygen levels are very low).

Fluorescent probes can be used to detect the presence of NTR with the photo-induced electron transfer (PET) mechanism. The PET structure consists of three main components. Firstly, the fluorophore absorbs light and emits fluorescence. Secondly, the receptor binds to the donor and transmits the message to the fluorophore via the third component, the spacer. When the fluorophore is excited, one electron from its highest-occupied molecular orbital (HOMO) is moved to its lowest-unoccupied molecular orbital (LUMO), allowing PET from the receptor's HOMO to the fluorophore's, which causes fluorescence quenching.

The use of the probes in NTR utilizes the concept of the domino reaction, a sequence of chemical reactions where the product of one reaction, acts as a reactant in the next sequential reaction [9]. This is initiated as NTR causes the reduction of the nitro group in the probe. This releases fluorophore and an optical change is observed as a result.

A separate study investigated how the NTR-responsive fluorescent probe worked [10]. Their results showed that the probe in the absence of NTR had a UV absorption band of 450nm with no fluorescence observed. Whereas the probe with the NTR presented a UV absorption band of 564nm with a strong fluorescence (586nm).

Limitations of the fluorescent probe

While zinc oxide is readily available, the fluorescent probe is more difficult to prepare. Its preparation requires several reactions and processes with several different molecules. As such, it's difficult to provide an estimate on its cost.

The probe concentration, delivery methods, and cellular localisation are some examples of variables that may have an impact on the probe's sensitivity. The photostability and potential cytotoxicity of the NTR-fluorescent probe should also be considered when planning experiments and analysing data. To get over these restrictions and increase the probe's usefulness, current research efforts are concentrated on enhancing the probe's selectivity, sensitivity, and compatibility with various experimental settings.

More importantly, there is very little information on how the probe will behave in the presence of zinc oxide. The probe relies on UV, while zinc oxide possesses properties of UV protection. Hence, this must be investigated further.

Component specifications

This section will describe the different layers of the wound dressing with the integration of the different materials.

Outer layer

The outer layer should be thin and weatherproof. It should keep the whole bandage intact and prevent anything from going in and out – should be a sufficient barrier. In order to utilize the probe accurately, it could be recommended to have a transparent outer layer to be able to properly view the colour change for bacterial detection. Furthermore, the outer layer should be breathable and non-irritant.

For these reasons, polyurethane was chosen as the most viable material for the outer layer. It has many desirable properties including good flexibility, tear, and water resistance [11]. Moreover, they function as a sort of barrier against bacteria, and have a transparent appearance. Finally, they have the ability to hold the hydrogel in place and can be used as the adhesive; to stick to the skin.

Inner (gel) layer

The inner layer is to be in direct contact with the wound. This is a hydrogel consisting of the fluorescent probe to detect bacterial infection and alert the patient with the colour change. And it also contains zinc oxide which provides antimicrobial resistance. The decision of either utilizing zinc oxide on its own or in the form of Cs/PVA zinc oxide, has yet to be made. While Cs/PVA zinc oxide possesses a lot of benefits, it's a more inconvenient and time-consuming process to prepare. Hence it might be more suitable to use zinc oxide alone; this would also be more affordable.

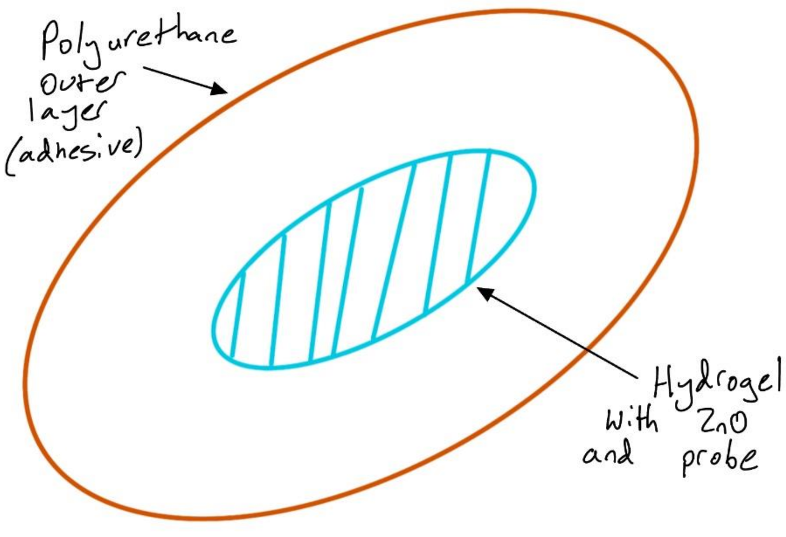

Figure 2 Sketch of product

The product features the hydrogel layer to be applied directly on the wound. It contains zinc oxide nanoparticles that provide antimicrobial resistance and responds to bacterial infection. The fluorescent probe is also integrated into the gel and will alert the wearer if bacteria is detected. Polyurethane acts as "backbone" and keeps the whole product together, and also sticks to the surrounding skin to keep the dressing on properly.

Conclusion

While there are promising technologies in wound dressings available for public use, implementing a component for bacterial detection is a new an innovative concept. By utilizing this, many problems can be prevented, typically infections. Furthermore, this concept creates the potential for more effective dressings in the industry.

There are however many more areas for improvement. Firstly, other nutrients for repair can be incorporated into the hydrogel matrix. This includes growth factors and other enzymes that can aid in and accelerate the regeneration of tissue. Additionally, the mechanical qualities of hydrogels can be improved further to offer better support and defence for the wound site. The hydrogel can demonstrate increased strength and stability, making it more resistant to deformation during the healing process, by modifying the crosslinking density or adding reinforcing agents.

Overall, research in wound care has improved dramatically, turning outdated techniques into the sophisticated wound dressings we have today. Significant advancements in wound care have been developed with the considerations of better design, material choice, and manufacturing methods, which encourages quicker healing and improved patient outcomes. Nevertheless, a deeper investigation in wound dressing techniques can lead to a more comprehensive understanding of wound healing mechanisms and pave the way for innovative approaches that revolutionize the field. By delving into the intricate interactions between dressings, wound microenvironment, and cellular responses, strategies to optimize healing outcomes can be uncovered.

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