

Fabrication of Self-Healing Absorbable Polymer-Based Gel for Wound Dressing [†]

Zaid Abdulhamid Alhulaybi ^{1,*}, Hawra Alhammaqi ², Masoumah Alatafi ², Reem Alamer ², Rayanah Aloudah ², Fatima Almarhoon ², Ghadeer Almohammed Saleh ², Walaa Althuwaini ² and Sarah Alamer ³

¹ Department of Chemical Engineering, College of Engineering, King Faisal University, Al-Ahsa 31982, Saudi Arabia

² Department of Biomedical Engineering, College of Engineering, King Faisal University, Al-Ahsa 31982, Saudi Arabia; 219027066@student.kfu.edu.sa (H.A.); 219040481@student.kfu.edu.sa (M.A.); 218008939@student.kfu.edu.sa (R.A.); 219012598@student.kfu.edu.sa (R.A.); 219016361@student.kfu.edu.sa (F.A.); 219030952@student.kfu.edu.sa (G.A.S.); 219037173@student.kfu.edu.sa (W.A.)

³ Department of Biology, College of Sciences, King Faisal University, Al-Ahsa 31982, Saudi Arabia; salamer@kfu.edu.sa

* Correspondence: zalhulaybi@kfu.edu.sa; Tel.: +966-13-589-7880

[†] Presented at the 4th International Electronic Conference on Applied Sciences, 27 October–10 November 2023; Available online: <https://asec2023.sciforum.net/>.

Abstract: Healthcare professionals must take special care of wounds to avoid serious complications such as infections, lengthy healing periods, and even amputations. This study aimed to design and manufacture a self-healing bioabsorbable polymeric-based wound dressing with antibacterial growth and improved wound healing properties. Gel-based mixtures were successfully made up of 5wt% chitosan with properties that inhibit bacterial growth in 5–20wt% polyvinyl alcohol (PVA) and called the “pure mixture”. It was observed that the mixture of 5wt% chitosan into 10wt% PVA resulted in the most controlled viscosity and appropriate gel texture for wound healing. The measured viscosities of 5wt% chitosan and 10wt% PVA were 235 and 531 Pa·s, respectively. A microscopic examination confirmed that the addition of chitosan into PVA successfully inhibited bacterial growth. Another gel-based mixture, named the “additive mixture”, was also investigated using the optimized preparation condition of 5wt% chitosan in 10wt% PVA with the incorporation of some traditional herbs in powder form, namely frankincense, myrrh, and alum stone. Microscopic examination proved that the addition of traditional herbs into the chitosan/PVA mixture inhibited some bacterial growth. A comparison of the wound healing performance of the pure mixture gel and additive mixture gel was conducted using rats. The pure mixture gel produced a faster healing rate and a lower level of inflammation than the additive mixture gel.

Keywords: composites; self-healing; polymers; absorbable; wound dressing



Citation: Alhulaybi, Z.A.; Alhammaqi, H.; Alatafi, M.; Alamer, R.; Aloudah, R.; Almarhoon, F.; Saleh, G.A.; Althuwaini, W.; Alamer, S. Fabrication of Self-Healing Absorbable Polymer-Based Gel for Wound Dressing. *Eng. Proc.* **2023**, *56*, 78. <https://doi.org/10.3390/ASEC2023-15233>

Academic Editor: Marco Annunziata

Published: 26 October 2023



Copyright: © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Skin is our largest organ, with a surface area of 1.8–2 m² and an approximate weight of 9 kg. The skin serves as a processor of sensory, thermoregulatory, metabolic, and immunological contact between the body's internal milieu and the external environment. Skin has the potential to easily become injured by sharp objects as it is a delicate organ. Wounds are injuries that damage or result in openings in the skin or other body tissues with multiple causes, such as sutures, stitches, and surgeries. Wounds initiate a complex healing process [1,2].

Wound dressing is utilized in order to aid the healing process [3]. There are two types of wound dressing, which are traditional and advanced wound dressing [4]. Wounds are a global health concern, yet technological advancements have not fully addressed wound

management [5]. This study aims to fabricate a self-healing bioabsorbable polymeric base with antibacterial and improved wound healing properties.

2. Materials

After optimizing the morphological conditions and accurately determining the essential standards for the design, the base materials were selected to be polyvinyl alcohol (PVA) and chitosan. These two polymers were chosen because of the characteristics and features mentioned in Table 1. Furthermore, combining synthetic and natural polymers will enhance the dressing properties.

Table 1. The chosen polymers that are compatible with the design requirements.

Polymer	Advantages	Role in Wound Healing	Reference
Chitosan	<ul style="list-style-type: none"> • Non-toxic • Biocompatible • Biodegradable • Safe • Antibacterial • Natural polymer • Hydrophilic 	<ul style="list-style-type: none"> • Preventing growth of bacteria • Preventing infection of the wound • Forming a gel 	[6,7]
Polyvinyl alcohol (PVA)	<ul style="list-style-type: none"> • Biodegradable • Harmless and non-toxic • Water-soluble • Natural hydrophilic • Bio-adhesive • Biocompatible • Non-carcinogenic • Synthetic polymer 	<ul style="list-style-type: none"> • Blending natural polymers with synthetic polymers • Taking advantage of its excellent mechanical properties 	[8]

Table 2 shows some possible additives that could be added to the polymer to enhance the quality of the dressing. The selection from the additives will be based on their efficacy during the practical trials.

Table 2. The possible additives that could be added to the polymer to enhance the quality of the dressing.

Possible Additives	Advantages	Role in Wound Healing	Reference
Frankincense	<ul style="list-style-type: none"> • Anti-inflammatory • Antibacterial • Antioxidant and anti-aging • Anticancer • Moisturizing • Antiseptic • Natural astringent • Safe • Absorbable 	<ul style="list-style-type: none"> • Preventing growth of bacteria • Preventing infection of the wound • Inflammation control • Improving wound healing 	[9,10]
Alum Stone	<ul style="list-style-type: none"> • Astringent • Hemostatic • Healing properties • Antibacterial • Anti-inflammatory • Anti-tumor • Water-soluble 	<ul style="list-style-type: none"> • Bleeding control • Accelerating wound healing • Reducing scars • Preventing growth of bacteria 	[11,12]

Table 2. Cont.

Possible Additives	Advantages	Role in Wound Healing	Reference
Rose Water	<ul style="list-style-type: none"> • Anti-inflammatory • Antibacterial • Antiseptic • Analgesic • Antioxidant and anti-aging • Safe 	<ul style="list-style-type: none"> • Accelerating wound healing • Reducing pain and scars • Preventing growth of bacteria • Reducing skin irritation 	[13]
Myrrh	<ul style="list-style-type: none"> • Antibacterial • Antimicrobial • Anti-inflammatory • Antioxidant • Healing properties 	<ul style="list-style-type: none"> • Improving skin texture • Enhancing wound contraction • Proliferating staged maturation of the blood vessels • Accelerating wound healing 	[14]

3. Method

Two mixtures were prepared for testing: a pure mixture consisting only of polymers, and an additive mixture containing additives.

The PVA mixture was prepared by heating distilled water to 90 °C, then adding 22.5 g of PVA to the water and stirring until completely dissolved. The final volume was 100 mL, with a 15% PVA concentration. To prepare the chitosan, 150 mL of distilled water was stirred with 7.5 g of chitosan, 5% Acetic acid, and 5% Acetic acid for 24 h. The final volume was 150 mL, with a 5% chitosan concentration. This mixture was blended with heat to create a gel-based texture. The additive mixture was prepared by adding frankincense, myrrh, alum stone, and rose water to 500 mL of rose water. This solution was finalized using a double filtration method, resulting in 400 mL of the additive solution. A blend of 50% pure chitosan and 50% PVA was combined with the additive solution, creating a gel-based texture. The gel was poured into an acrylic mold, covered with non-stick and non-woven paper, and left to solidify for two to three days. The adhesive gel was then applied to a DAMA transparent adhesive dressing.

A bacterial growth test was conducted using a development buffer (DB) made of 8 mL PBS, 24 mL distilled water, 4 mL MgCl₂, and 4 mL CaCl₂. Agar powder was added to the DB to provide a stable growth surface for bacteria to form colonies. The mixture was sterilized by being holed for 15 min at 121 °C in an autoclave. The initial investigative test involved wiping three sample plates with a pre-sterilized DB mixture, pure mixed polymers, and composite polymers and additives, then adding 4 mL of a media buffer (MB) under UV light for 20 min, which enhanced the growth of microorganisms and the fermentation of the environment. As a second investigative test, the MB solution was separated from the sample plates and poured into two bottles with a small amount of distilled water and 0.5 mL iodine. This solution was centrifuged for four minutes to separate the particles, creating a strong bacterial environment for the testing operation. Then, three sample plates were wiped with a pre-sterilized DB mixture, pure mixed polymers, and composite polymers and additives. A total of 4 mL of mononuclear and iodine agent solution was added to each plate and kept at room temperature for four days.

After obtaining ethical approval from the deanship of scientific research, we acquired three rats to evaluate their wound-healing process by making minor cuts (superficial wounds) on their body under local anesthetic. Then, we wiped the first rat's wound with the pure mixture of polymers, the second one with the mixture of polymers and additives,

and the third without any solution, to be considered a control sample. The wounds were monitored for four days.

The viscosity of a mixture was determined through four practical steps: determining the weight of the pure polymer mix and the composite polymer mix with additives; calculating the volume using normative beakers and calculating the density of both mixtures. These data were then applied to the mathematical formula to determine their viscosity.

4. Result

The results of the bacteria growth test are shown in the Figures 1 and 2.

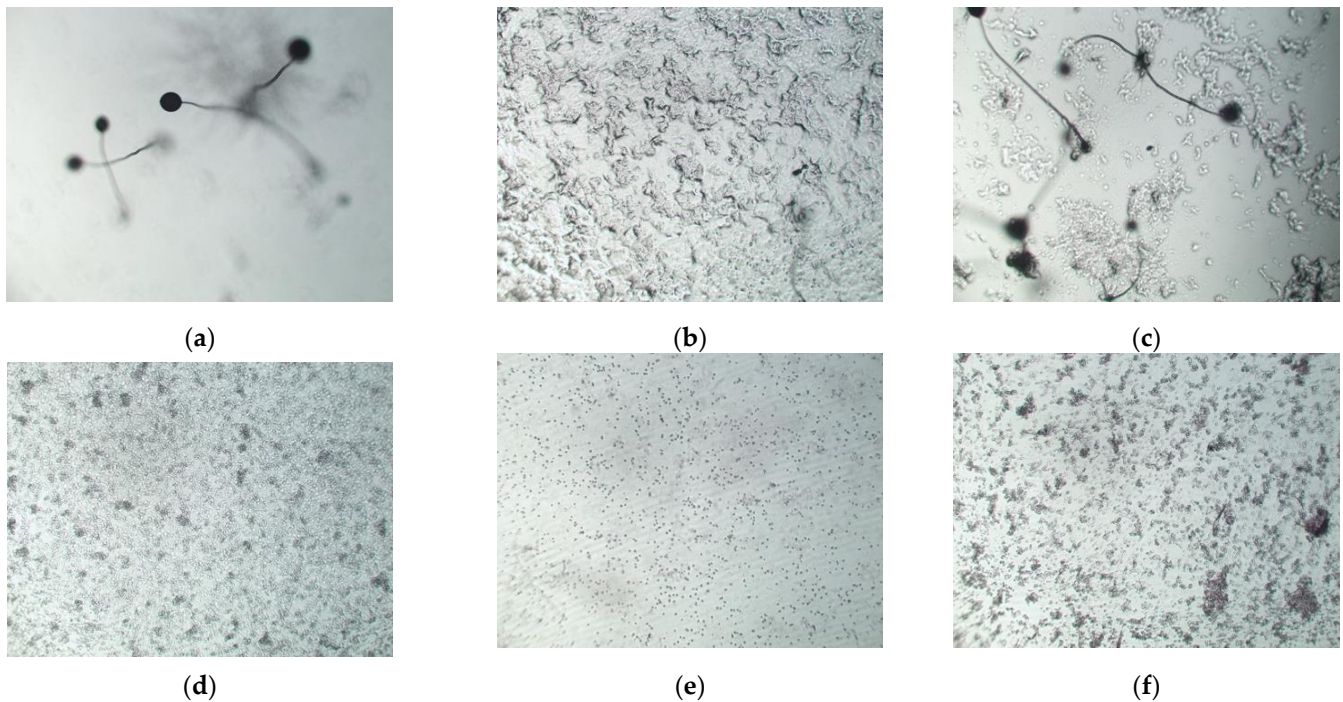


Figure 1. The results of the bacterial growth test under a microscope. (a) Bacterial development of the control specimen; (b) bacterial growth on the control plates; (c) bacterial development of the pure mixture; (d) bacterial growth on the plates wiped with the pure mixture; (e) bacterial development of the additive mixture; and (f) bacterial growth on the plates wiped with the additive mixture.

The effectiveness of each mixture was assessed in lab rats and the wound healing duration was monitored. The following figure shows the results once the lab rats had been monitored for four days, after applying the gel once, directly after incision.

After the fabrication, the first test performed was a physical properties test that included measuring the viscosities of the mixtures. Table 3 shows the calculated viscosity results.

Table 3. The viscosity test results.

Polymeric Concentration	Viscosity (Kg/m.s)
PVA 5%	2.1319
PVA 10%	531.1847
PVA 20%	4032.1501
CH 5%	235.1173

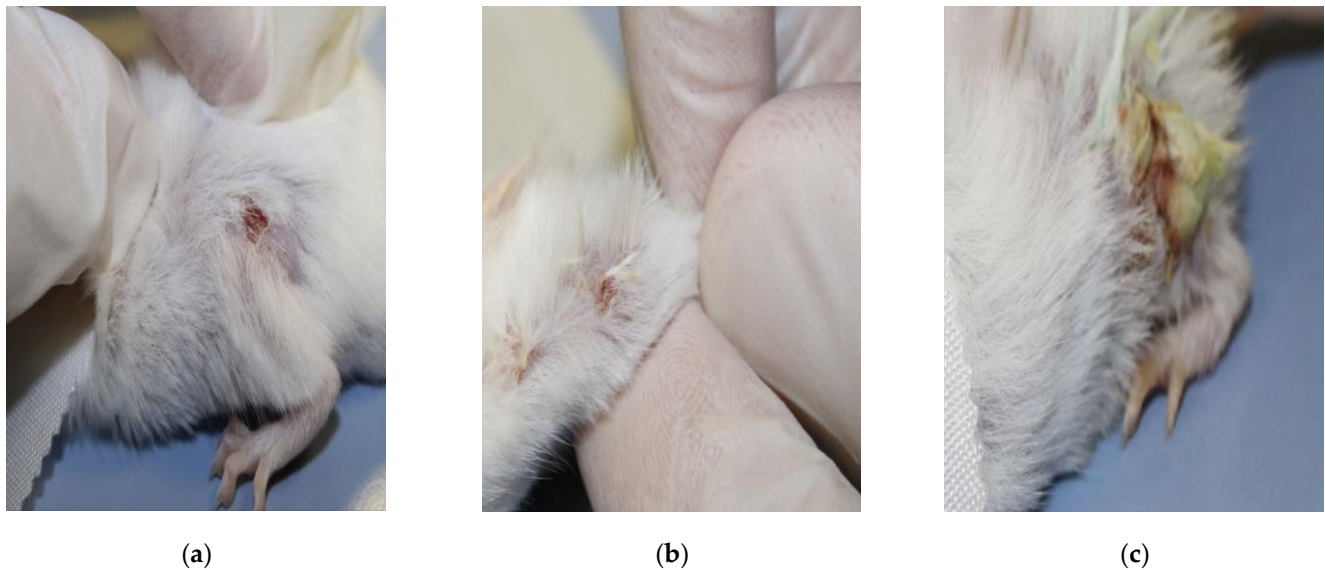


Figure 2. The healing effectiveness of the fabricated wound dressing. (a) The healing result of the control rat; (b) the healing result after applying the pure mixture on the rat; (c) the healing result after applying the additive mixture on the rat.

5. Discussion

The control plates showed clear and significant cell aggregation as well as a large number of fruiting bodies, indicating normal cell growth. The plates containing the pure gel mixture showed no aggregation or cell development on the growth plate and no fruiting bodies on the development plate. This indicates that the mixture had a strong inhibitory effect on microbial growth. The final two plates were used with the additive mixture: the growth plate showed some aggregation and fungi, but the aggregation was not as significant as the control; and the development plate showed some fruiting bodies, though most were dead. This indicates that the mixture had a partly inhibitory effect, but not as strong as the pure gel mixture.

The rats were monitored for four days after applying the gel once directly after incision. For the pure mixture, the results were promising compared to the control rat, showing a reduction in wound size. Meanwhile, the additive mixture did not show any enhancement of wound healing, and made the wound look inflamed.

When the gel made from chitosan and PVA was molded on a medical pad, it worked well for healing wounds. It helped wounds heal faster, initiated new skin growth, and stopped bacteria from growing. The pure gel showed the best results. This gel is affordable, easy to obtain, safe, and suitable for people with allergies.

6. Conclusions and Future Work

The chitosan and PVA polymer-based gel formed an effective wound dressing when applied to a medical pad. It showed promising results in accelerating wound healing, promoting new skin formation, and inhibiting bacterial growth. Testing showed that the pure polymer gel mixture was most effective, while the additive-containing mixture provided few benefits. This suggests that the chitosan–PVA base itself is what is effective. The polymer gel dressing’s affordability, accessibility, safety, and hypoallergenic properties make it a promising option. However, further research and optimization are still needed before commercializing this product. Future work could improve the prototype through advanced manufacturing techniques to make it suitable for post-surgical wounds instead of sutures. Additionally, incorporating local natural materials from Al-Ahsa could give the product a distinctive cultural theme while contributing to the development of national industries. While the initial results are promising, substantial research and development are still needed before this polymer dressing can be routinely used as an accepted treatment.

Nevertheless,, with focused efforts and refinement, this novel dressing has the potential to become a valuable treatment option in the near future.

Author Contributions: Conceptualization, Z.A.A. and S.A.; methodology, H.A.; software, M.A.; validation, F.A. and W.A.; formal analysis, R.A. (Reem Alamer); investigation, G.A.S.; resources, M.A.; data curation, R.A. (Rayanah Aloudah); writing—original draft preparation, H.A., Alatafi, M., R.A. (Reem Alamer), R.A. (Rayanah Aloudah), F.A., G.A.S. and W.A.; writing—review and editing, Z.A.A. and S.A.; visualization, S.A.; supervision, Z.A.A.; project administration, M.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: With due consideration for animal welfare, animal testing must be conducted ethically and humanely. Our experiment was ethically conducted with the approval of King Faisal University, ensuring responsible and ethical conduct. The ethical approval number is KFU-REC-2023-JAN-ETHICS493.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are contained within the article.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Değim, Z. Use of microparticulate systems to accelerate skin wound healing. *J. Drug Target.* **2008**, *16*, 437–448. [CrossRef] [PubMed]
2. Wounds and Injuries. Available online: <https://medlineplus.gov/woundsandinjuries.html> (accessed on 20 September 2023).
3. Dreifke, M.B.; Jayasuriya, A.A.; Jayasuriya, A.C. Current wound healing procedures and potential care. *Mater. Sci. Eng. C* **2015**, *48*, 651–662. [CrossRef] [PubMed]
4. Tottoli, E.M.; Dorati, R.; Genta, I.; Chiesa, E.; Pisani, S.; Conti, B. Skin Wound Healing Process and New Emerging Technologies for Skin Wound Care and Regeneration. *Pharmaceutics* **2020**, *12*, 735. [CrossRef] [PubMed]
5. EL-Ghoul, Y.; Alminderej, F.M.; Alsubaie, F.M.; Alrasheed, R.; Almousa, N.H. Recent Advances in Functional Polymer Materials for Energy, Water, and Biomedical Applications: A Review. *Polymers* **2021**, *13*, 4327. [CrossRef] [PubMed]
6. Matica, M.A.; Aachmann, F.L.; Tøndervik, A.; Sletta, H.; Ostafe, V. Chitosan as a Wound Dressing Starting Material: Antimicrobial Properties and Mode of Action. *Int. J. Mol. Sci.* **2019**, *20*, 5889. [CrossRef] [PubMed]
7. Cao, J.; Wu, P.; Cheng, Q.; He, C.; Chen, Y.; Zhou, J. Ultrafast Fabrication of Self-Healing and Injectable Carboxymethyl Chitosan Hydrogel Dressing for Wound Healing. *ACS Appl. Mater. Interfaces* **2021**, *13*, 24095–24105. [CrossRef] [PubMed]
8. Gaaz, T.; Sulong, A.; Akhtar, M.; Kadhum, A.; Mohamad, A.; Al-Amiery, A. Properties and Applications of Polyvinyl Alcohol, Halloysite Nanotubes and Their Nanocomposites. *Molecules* **2015**, *20*, 22833–22847. [CrossRef] [PubMed]
9. 15 Uses and Benefits of Frankincense Essential Oil. iLAVAHEMP. Available online: <https://ilavahemp.com/frankincense-essential-oil/> (accessed on 23 September 2023).
10. 5 Benefits and Uses of Frankincense—And 7 Myths. Available online: <https://www.healthline.com/nutrition/frankincense#> (accessed on 23 September 2023).
11. Alum: Benefits, Precautions and Dosage. 1 mg. Available online: <https://www.1mg.com/ayurveda/alum-143> (accessed on 23 September 2023).
12. Pal, D.A. Alum: Uses, Benefits & Side Effects. PharmEasy Blog. 25 April 2022. Available online: <https://pharmeasy.in/blog/ayurveda-uses-benefits-side-effects-of-alum/> (accessed on 23 September 2023).
13. Rose Water: 10 Benefits and How to Use. Available online: <https://www.healthline.com/health/rose-water-benefits> (accessed on 23 September 2023).
14. Suliman, R.S.; Alghamdi, S.S.; Ali, R.; Aljatl, D.; Aljammaz, N.A.; Huwaizi, S.; Suliman, R.; Kahtani, K.M.; Albadrani, G.M.; Barhoumi, T.; et al. The Role of Myrrh Metabolites in Cancer, Inflammation, and Wound Healing: Prospects for a Multi-Targeted Drug Therapy. *Pharmaceutics* **2022**, *15*, 944. [CrossRef] [PubMed]

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.