medical sciences forum

MDPI

Proceeding Paper

The Optimization of a Polyvinyl Alcohol and Gum Tragacanth Membrane with Ciprofloxacin-Loaded Gold Nanoparticles for Wound Healing Applications †

Hadiya Malik [1], Nosheen Fatima Rana [1,*], Tehreem Tanweer [1] and Farid Menaa [2]

1 Department of Biomedical Engineering and Sciences, School of Mechanical & Manufacturing Engineering, National University of Science & Technology, Islamabad 44000, Pakistan; hmalik.bme21smme@student.nust.edu.pk (H.M.); ttanweer.phd19smme@student.nust.edu.pk (T.T.)
2 Departments of Internal Medicine and Nanomedicine, California Innovation Corporation, San Diego, CA 92037, USA; menaateam@gmail.com
* Correspondence: nosheen.fatima@smme.nust.edu.pk; Tel.: +92-5190856074; Fax: +92-5190856002
† Presented at the 3rd International Electronic Conference on Antibiotics (ECA 2023), 1–15 December 2023; Available online: https://eca2023.sciforum.net/.

Abstract: Bandages, gauzes, and alcoholic pads have been widely used for wound healing. However, bacterial infection in wounds is still a major problem and needs to be explored. Apart from antibacterial activity, the hydrophilicity of a membrane is also a major characteristic of membranes that should be explored. Upon contact with wound exudates, the hydrophilic membranes absorb water, swell, and liquefy to form a gel over the wound, which enhances autolytic debridement. Keeping this in view, this study aimed to synthesize and optimize a Polyvinyl Alcohol (PVA) and Gum Tragacanth (GT) membrane having different concentrations of gold nanoparticles (AuNPs) loaded with Ciprofloxacin (CIP) and their effect on the hydrophilicity of the membranes. CIP-AuNPs were prepared by the Turkevich method, and then for confirmation FTIR was performed. Membranes with different concentrations of CIP-AuNPs incorporated in PVA/GT and analyzed for their hydrophilicity. A membrane swelling ratio test as well as contact angle analysis were performed. Through this study, it was concluded that hydrophilic membrane of PVA/GT having a 5% concentration of CIP-AuNPs can be used as a wound healing material.

Keywords: wound healing; antibacterial activity; PVA/GT

Citation: Malik, H.; Rana, N.F.; Tanweer, T.; Menaa, F. The Optimization of a Polyvinyl Alcohol and Gum Tragacanth Membrane with Ciprofloxacin-Loaded Gold Nanoparticles for Wound Healing Applications. *Med. Sci. Forum* **2024**, *24*, 6. https://doi.org/10.3390/ECA2023-16387

Academic Editor: Marc Maresca

Published: 30 November 2023

1. Introduction

Skin, as the body's biggest tissue, plays an important homeostatic part, in addition to its protective purpose. In typical conditions, the epidermis has a self-healing process after being subjected to acute injury [1]. Infection is the most frequent cause of an acute wound becoming a chronic non-healing wound [2]. An ideal wound dressing can: (a) provide adequate long-lasting contact between the dressing and the skin area around the wound to absorb secretions exuded from the wound, (b) maintain a moist around the area of the wound, and (c) protect the wound from heat and allow air to pass through. There are bandages, gauzes, alcoholic pads, and other wound care products on the market, but each has a few limitations [3].

Nanobiotechnology developments have assisted in the creation of wound-healing materials that are both cost-effective and efficient. Polyvinyl Alcohol (PVA) is a highly robust polyhydroxy polymer with outstanding adhesion properties. Because of its membrane-forming and watery characteristics, is extensively used as a cross-linker. It is non-toxic, water-soluble, and biodegradable, and has excellent heat properties. However, using PVA hydrogel alone as a wound therapy polymeric material has some limitations, due to its less hydrophilic characteristics and insufficient elasticity. These limitations can be circumvented by crosslinking and combining PVA with other biopolymers [4].

Gum Tragacanth (GT) is a well-known natural substance with beneficial characteristics such as non-toxicity, biocompatibility, availability, and biodegradability. Due to these properties, GT is useful for epidermis healing and medication carrier applications. The mineral components of GT, such as calcium, magnesium, and potassium, aid in wound recovery. Calcium presence is required for epidermal cell migration and renewal. Magnesium aids in the proliferation and remodeling phases of wound healing [5]. Unadulterated GT nanofiber formation, however, is restricted due to its unique chemical structure, and should be mixed with biodegradable polymers such as PVA [6].

Several nano-drug delivery techniques for skin tissue regeneration have been discovered and implemented [7]. Drug delivery carrier nano particles (NPs), such as gold nanoparticles (AuNPs) and silver nanoparticles (AgNPs), are known to be effective in treating a variety of medical conditions, including bacterial, viral, and fungal infections [8]. In vitro wound healing in rats was compared to AuNP and AgNP monotherapy; AuNP treatment demonstrated significant free radical scavenging activity as well as improved wound healing [9].

Many wound infections are produced by bacteria, e.g., *Escherichia coli* and *Staphylococcus aureus*, are one of the most critical problems in the wound healing process [10]. In this respect, bacterial infections of the incision must be avoided for wound recovery, and various antibacterial medicines have been used, of which Ciprofloxacin (CIP) is the one of the most well-known antibiotics. Its antibacterial action includes both Gram-negative and Gram-positive bacteria, making it useful in treating a broad variety of wound infections [11].

The current research aims to synthesis and characterize PVA hydrogel coupled with GT having different concentrations of AuNPs loaded with CIP for wound healing.

2. Materials and Methods

2.1. Materials

GT was purchased from a local store. Sigma Aldrich (Burlington, Massachusetts) supplied PVA (MW = 72,000 Da), Trisodium citrate, AuCl4, and Ciprofloxacin.

2.2. Synthesis of AuNPs and CIP-AuNPs

The AuNPs were prepared by the Turkevich method, which is a very convenient technique to obtain the sphere-shaped AuNPs by using AuCl4 (0.5 mM), which acts as a reducing as well as stabilizing agent, and chloroauric acid (0.5 mM). Both solutions were mixed, and the formation of particles was verified when a red wine color was obtained. A total of 20 mL of the above solution at pH 6.5 was combined with 5 mL of CIP (0.5 mM) to load CIP on AuNPs. The solution was then stirred until the red color changed to bluish purple [12].

2.3. Synthesis of the Membrane

Membranes were prepped by casting method by dissolving different ratios (1%, 2.5%, and 5%) of nanoparticles in PVA/GT (Table 1) and then poured into Petri dishes. The solutions were left to dry for 24 h.

Table 1. This table shows the different concentrations of CIP-AuNPs in the PVA/GT membrane.

Concentration of PVA/GT.	Concentration of CIP-AuNPs
6:4	0%
6:4	1%
6:4	2.5%
6:4	5%

2.4. Characterization

By using the FTIR, AuNPs and CIP-AuNPs were characterized.

2.5. Swelling Ratio and Contact Angle

The swelling ratio was calculated to assess the membranes' water absorption capacity. The dry membranes (1 × 1 cm, length × width) were weighed and then submerged in water for 24 h. After 24 h, excess water was wiped off with clean paper and then they were again weighed. The swelling ratio is calculated as follows:

$$\text{Swelling ratio (\%)} = (\text{Ws} - \text{Wd})/\text{Wd}\ 100\%,$$

where Wd and Ws represent the dry and swollen weight, respectively [13].

The sessile drop method was used for contact angle measurement at 20 °C to determine the membrane hydrophilicity. The contact angle was determined by dropping few drops of water on the membrane's surface at a time. This process was repeated three times for each sample, and the result was averaged.

3. Results and Discussion

3.1. FTIR

FTIR spectra were collected in the range of 1000 to 4000 cm^{-1}. The FTIR spectrum in the image (Figure 1) shows the successful adsorption of ciprofloxacin (CIP) in gold nanoparticles (AuNPs) by observing the bands stretching at different wavelengths. As the N-H stretching band from 3316 cm^{-1} to 3449 cm^{-1} shows that CIP has been observed by AuNPs. The O-H stretching band appeared large in the spectrum of CIP-AuNPs, and citrate traces are responsible for the faint bands in the CIP-AuNPs at about 2918 cm. This shows that water in small amounts, along with citrate, is present in CIP-AuNPs which were used for the preparation of nanoparticles.

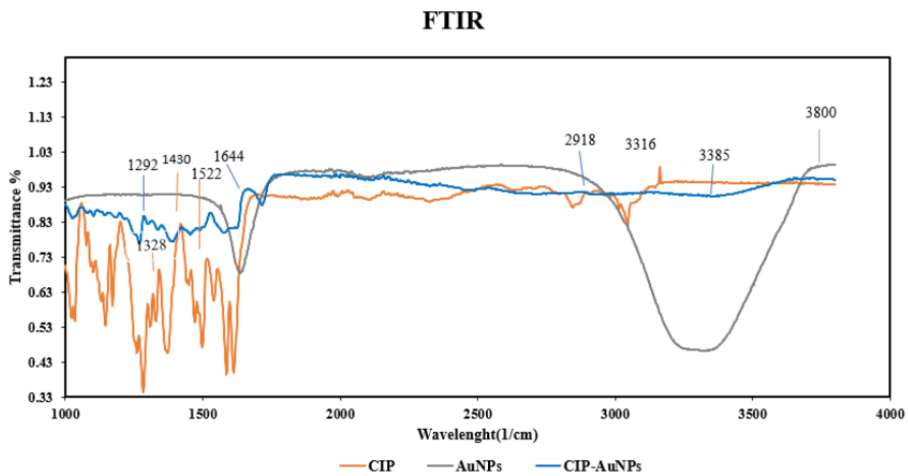

Figure 1. FTIR of CIP, AuNPs and CIP-AuNPs.

3.2. Swelling Ratio and Contact Angle

The swelling ratio is a practical method for determining a material's capacity for water absorption. The swelling ratio of each membrane was depicted in Figure 2. At 24 h, the swelling ratio of pure PVA/GT was 272.6%. The swelling ratios of the membranes loaded with NPs were 242.3%, 227.1%, and 221.6%, respectively. The results indicated that these membranes have a high capacity for water absorption (Figure 2).

The water contact angle of a material indicates its hydrophilicity. Overall, the smaller the contact angle, the greater a material's hydrophilicity [14]. The water contact angles of M1, M2, M3, and M4 were 54.4, 52, 47.1, and 44, respectively (Figure 3). The films were hydrophilic because all water contact angles were less than 90 degrees. The water contact angle decreased, which could be attributed to the difference in CIP-AuNP concentration.

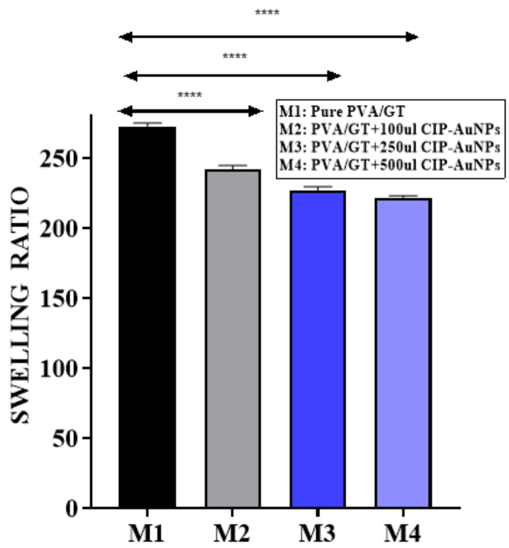

Figure 2. Swelling ratio of pure PVA/GT, PVA/GT loaded with 1% CIP-AuNPs, PVA/GT loaded with 2.5% CIP-AuNPs, PVA/GT and PVA/GT loaded with 5% CIP-AuNPs. **** shows statistically significant results as the *p* value is less than 0.005.

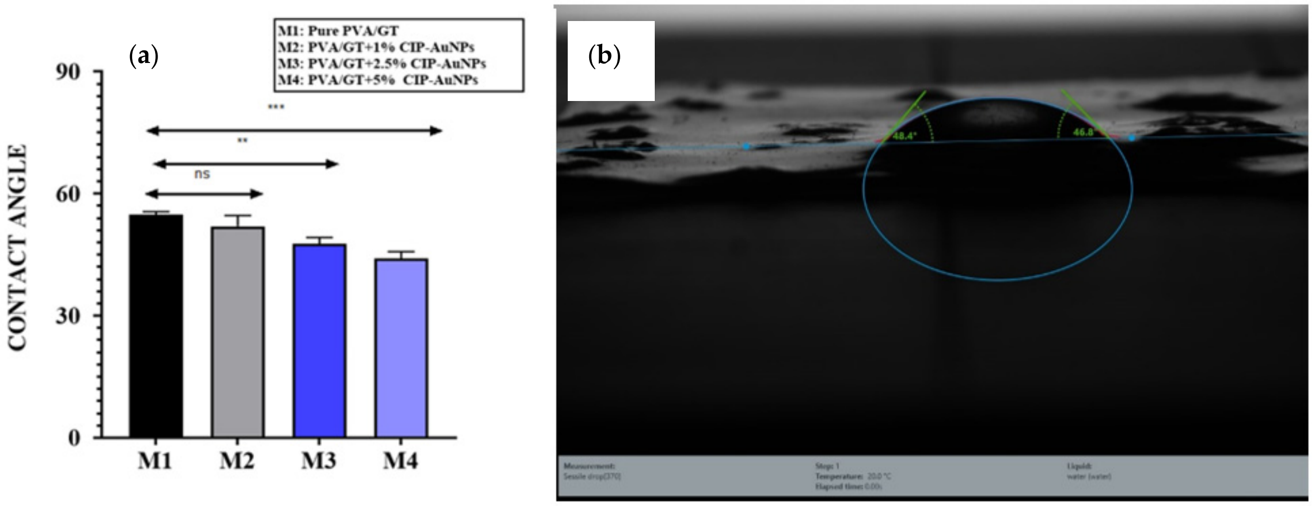

Figure 3. The contact angle of (**a**) pure PVA/GT, PVA/GT loaded with 1% CIP-AuNPs, PVA/GT loaded with 2.5%CIP-AuNPs, and PVA/GT loaded with 5% CIP-AuNPs. ns shows statistically insignificant results as the *p* value is greater than 0.005, while *** and ** shows statistically significant results as the *p* value is less than 0.005. (**b**) The contact angle of PVA/GT loaded with 5% CIP-AuNPs.

4. Conclusions

A cost-effective and eco-friendly strategy was developed in which nanoparticles of gold were loaded in Ciprofloxacin, a well-known antibiotic, mixed with a membrane of PVA/GT. The resultant membrane not only requires hydrophilicity and high-water absorption, but also exhibits excellent antibacterial wound healing activity, and can be used for wound healing and skin regeneration.

Author Contributions: Supervision and project administration, N.F.R.; Conceptualization, T.T. and N.F.R.; Methodology, T.T. and H.M.; Software, H.M. and T.T.; Validation, N.F.R.; Formal analysis, data curation and investigation, N.F.R., T.T., H.M. and F.M.; Resources, N.F.R. and F.M.; writing—original draft preparation, H.M. and T.T.; Writing—review and editing, T.T., N.F.R., H.M. and F.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are contained within the article.

Acknowledgments: Many thanks to the different departments of National University of Science and Technology, Islamabad, Pakistan, for providing their guidance and lab services.

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

References

1. Bellu, E.; Medici, S.; Coradduzza, D.; Cruciani, S.; Amler, E.; Maioli, M. Nanomaterials in Skin Regeneration and Rejuvenation. *Int. J. Mol. Sci.* **2021**, *22*, 7095. [CrossRef] [PubMed]
2. Khan, A.U.R.; Huang, K.; Khalaji, M.S.; Yu, F.; Xie, X.; Zhu, T.; Morsi, Y.; Jinzhong, Z.; Mo, X. Multifunctional bioactive core-shell electrospun membrane capable to terminate inflammatory cycle and promote angiogenesis in diabetic wound. *Bioact. Mater.* **2021**, *6*, 2783–2800. [CrossRef]
3. Yu, K.; Lu, F.; Li, Q.; Zou, Y.; Xiao, Y.; Lu, B.; Liu, J.; Dai, F.; Wu, D.; Lan, G. Accelerated wound-healing capabilities of a dressing fabricated from silkworm cocoon. *Int. J. Biol. Macromol.* **2017**, *102*, 901–913. [CrossRef] [PubMed]
4. Mousa, M.; Dong, Y. Strong poly (vinyl alcohol)(PVA)/bamboo charcoal (BC) nanocomposite films with particle size effect. *Acs Sustain. Chem. Eng.* **2018**, *6*, 467–479. [CrossRef]
5. Ranjbar-Mohammadi, M.; Rabbani, S.; Bahrami, S.H.; Joghataei, M.; Moayer, F. Antibacterial performance and in vivo diabetic wound healing of curcumin loaded gum tragacanth/poly(ε-caprolactone) electrospun nanofibers. *Mater. Sci. Eng. C* **2016**, *69*, 1183–1191. [CrossRef] [PubMed]
6. Ranjbar-Mohammadi, M.; Kargozar, S.; Bahrami, S.H.; Joghataei, M. Fabrication of curcumin-loaded gum tragacanth/poly(vinyl alcohol) nanofibers with optimized electrospinning parameters. *J. Ind. Text.* **2017**, *46*, 1170–1192. [CrossRef]
7. Alven, S.; Aderibigbe, B.A. Fabrication of Hybrid Nanofibers from Biopolymers and Poly (Vinyl Alcohol)/Poly (ε-Caprolactone) for Wound Dressing Applications. *Polymers* **2021**, *13*, 2104. [CrossRef] [PubMed]
8. Uzair, B.; Liaqat, A.; Iqbal, H.; Menaa, B.; Razzaq, A.; Thiripuranathar, G.; Rana, N.F.; Menaa, F. Green and Cost-Effective Synthesis of Metallic Nanoparticles by Algae: Safe Methods for Translational Medicine. *Bioengineering* **2020**, *7*, 129. [CrossRef] [PubMed]
9. Kushwaha, A.; Goswami, L.; Kim, B.S. Nanomaterial-Based Therapy for Wound Healing. *Nanomaterials* **2022**, *12*, 618. [CrossRef] [PubMed]
10. Bruellhoff, K.; Fiedler, J.; Möller, M.; Groll, J.; Brenner, R.E. Surface Coating Strategies to Prevent Biofilm Formation on Implant Surfaces. *Int. J. Artif. Organs* **2010**, *33*, 646–653. [CrossRef] [PubMed]
11. Yang, J.; Wang, K.; Yu, D.-G.; Yang, Y.; Bligh, S.W.A.; Williams, G.R. Electrospun Janus nanofibers loaded with a drug and inorganic nanoparticles as an effective antibacterial wound dressing. *Mater. Sci. Eng. C* **2020**, *111*, 110805. [CrossRef] [PubMed]
12. Tom, R.T.; Suryanarayanan, V.; Reddy, P.G.; Baskaran, S.; Pradeep, T. Ciprofloxacin-Protected Gold Nanoparticles. *Langmuir* **2004**, *20*, 1909–1914. [CrossRef] [PubMed]
13. Matar, G.H.; Andac, M.; Elmas, A. Locust bean gum-polyvinyl alcohol hydrogels: Synthesis, characterization, swelling behaviors, and mathematical models. *J. Appl. Polym. Sci.* **2022**, *139*, 51498. [CrossRef]
14. Li, W.; Huang, Z.; Cai, R.; Yang, W.; He, H.; Wang, Y. Rational Design of Ag/ZnO Hybrid Nanoparticles on Sericin/Agarose Composite Film for Enhanced Antimicrobial Applications. *Int. J. Mol. Sci.* **2020**, *22*, 105. [CrossRef] [PubMed]