RESEARCH
www.commprac.com
ISSN 1462 2815

HYALURONIC ACID/ POLYVINYL ALCOHOL ELECTROSPUN NANOFIBER WITH CURCUMIN NANOPARTICLES FOR WOUND DRESSINGS

Amba Esakki [1], Dr. Prabhalakshmi [2]* and Dr. Dhanraj Ganapathy [3]

[1] Saveetha Dental College and Hospital, Saveetha Institute of Medical and Technical Science, Saveetha University, Chennai. Email: 152101005.sdc@saveetha.com
[2] Senior Lecturer, Department of Prosthodontics, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences [SIMATS], Saveetha University, No. 162, Poonamallee High Road, Velappanchavadi, Chennai.
*Corresponding Author Email: prabhalakshmikb.sdc@saveetha.com
[3] Professor & Head, Department of Prosthodontics, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences (SIMATS), Saveetha University, Chennai, Tamil Nadu, India. Email: dhanraj@saveetha.com

DOI: 10.5281/zenodo.11408738

Abstract

Introduction: PVA is a synthetic water-soluble polymer, widely used in biomedical and pharmaceutical applications because of its biocompatibility, biodegradability, and non-toxic properties. The presence of hydroxyl groups on PVA increases its hydrophilicity and capacity to create good physical/chemical interaction with other molecules. Hyaluronic acid helps skin stretch and flex and reduces skin wrinkles and lines. Hyaluronic acid is also proven to help wounds heal faster and can reduce scarring. Aim: To synthesize, characterise and check the biocompatibility of PVA/HA nanofiber membrane loaded with curcumin nanoparticles for wound dressing. Materials & methods: To create a nanofibrous mat from the mixture of PVA and curcumin at two different mixing ratios, two electrospinning solutions were made. Results: In our research the nanofibers made of PVA/HA - CURCUMIN had a good cell viability rate of 85% which makes us confirm that it is a good biocompatible substance. Conclusion: Our study proposes a method for the preparation of PVA/HA nanofiber membranes with good cytocompatibility and degradation resistance. Further studies should be done in animal model.

Keywords: Biocompatibility, Curcumin, Electrospin, Healing, Nanofiber.

INTRODUCTION

A naturally occurring polysaccharide, hyaluronic acid is used as a viscoelastic tool due to its unique physicochemical features.(1) Hyaluronic acid is a naturally occurring glycosaminoglycan that functions as an eye lubricant as well as a lubricating and shock-absorbing fluid in joints due to its viscosity, elasticity, and other rheological qualities. (2)HA is a key element in the soft periodontal tissues, gingiva, and periodontal ligament, and in the hard tissue, such as alveolar bone and cementum.(3) The high molecular weight HA produced by hyaluronan synthase enzymes in periodontal tissues, gingiva, periodontal ligament, and alveolar bone undergoes extensive degradation to lower molecular weight molecules in chronically inflamed tissue, like gingival tissue inflammation, or in the recovery period following implant or sinus lift surgery.(4) One of the most hydrophobic compounds in nature is HA.(5) Hydrogen bonding between adjacent carboxyl and N-acetyl groups occur when HA is introduced into an aqueous solution; this property enables HA to maintain conformational rigidity and to hold onto water.(4,6) Additionally, HA has vital viscoelastic qualities that inhibit the entry of germs and viruses into tissue.(7) The molecule plays a significant role in the stages of tissue remodeling, granulation tissue formation, inflammation, and wound healing in both mineralized and non-mineralized tissues. (8,9)

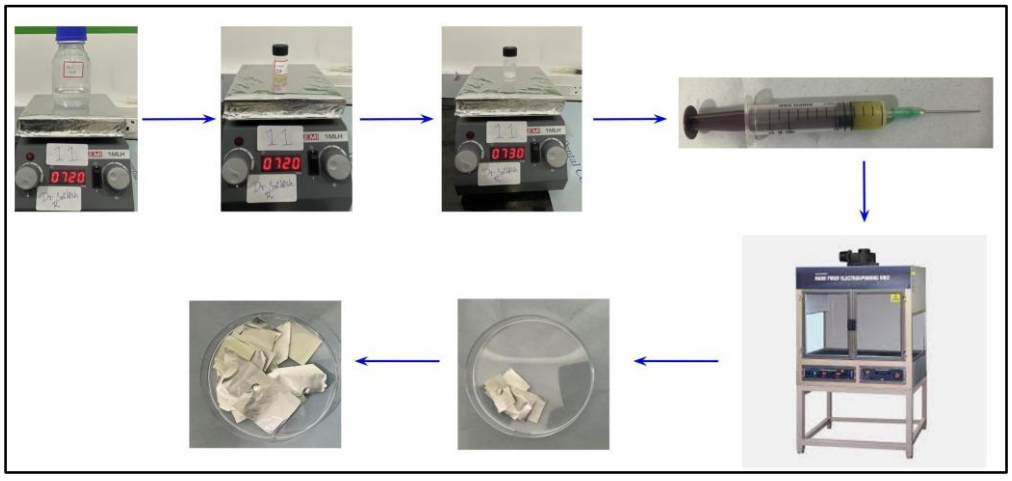
The synthetic polymers polyvinyl alcohol (PVA) have good stability for bone repair and regeneration.(10) Biomedical applications have made use of polyvinyl alcohol due to its highly advantageous physicochemical and biocompatibility traits.(11) Previous investigations have revealed that it exhibits more mechanical stability than other polymers.(12) PVA, however, degrades extremely gradually. (13)One of the best biodegradable polymers and a common medicine carrier is PVA. It breaks down into harmless byproducts.(14) However, PVA doesn't promote cell adhesion.(15) Additionally, their mechanical support is weak. According to one study, adding HA to a polymer scaffold like PVA improved the adhesion, mineralization, and metabolic activity of osteoblasts.(13,16)

The use of medicinal plants to treat human skin, including the healing of wounds and burn injuries has a long history and is still used in basic healthcare today.(13,16,17) Typically, wound dressing materials which are mostly made from textile fabric with metal nanoparticles to impart antibacterial or other desirable properties are widely utilized for the treatment of skin wounds. (18)

Some significant needs for a plant material to be utilized as wound dressing materials include maintaining a protecting the wound from side infection, minimizing wound surface necrosis, preventing wound dryness, biocompatibility and biodegradability. (18,19)(20,21)

Natural, synthetic, and composite polymers that have at least one of their three dimensions in the nanoscale are known as polymeric nanomaterials.(22) They are made using one of the nano-approach techniques.(20) Electrospinning has become a widely acknowledged technique for producing nanofiber due to its effectiveness, simplicity, adaptability, and simplicity of use. (22,23)An easy-to-use method called electrospinning uses the electrostatic attraction of opposing surface charges to constantly extract nanofibers out of a viscoelastic fluid.(24) When a high-voltage electrostatic field is applied between the needle tip and the collector during electrospinning, fibers are created as the solvent evaporates.(25)(20) By having a high surface area to volume ratio, high tensile strength, high compressibility, good biodegradability, and similarity to the extracellular matrix, the generated nanofibers can create scaffolds with better physical, chemical, and biological properties.(26) The current study aims in the process of nano fibre formation from PVA/ ha+ curcumin and estimation of its properties for wound dressing.

MATERIALS AND METHODS



Materials:

First, curcumin was purchased at a local market in Chennai city. PVA granules with a MW of 115,000, DP of 1700–1800, viscosity of 26–32 cps, and 99% hydrolyzed composition were purchased from Loba Chemical Pvt. Ltd. in India. From Merck in Germany, reagent-grade acetic acid (99.7% purity) and 99% pure ethyl acetate were purchased. None of the compounds or solvents were further purified before use.

Preparation of Curcumin Extract:

Curcumin was examined to make sure the materials were clean and free of contaminants prior to extraction. A little piece of curcumin was then oven-dried at 45°C and pulverized in a room-temperature electronic grinder. Three separate overnight soaks in ethyl acetate at a ratio of 1:10 (w/v%) were performed on the powder samples. Then, three times of nylon mesh were used to filter the crude curcumin extract. The solvent was eventually extracted from the curcumin extracts at 40°C using a magnetic stirrer, and it was stored at 4°C for further use.

To create a 10 wt% (w/v) solution, 10 g of PVA were combined with 90 mL of deionized water. To obtain a clear and transparent solution, the mixture was agitated and heated to 80°C.

Preparation of Nano Fibre:

To create a nanofibrous mat from the mixture of PVA and curcumin at two different mixing ratios, two electrospinning solutions were made. The first solution, known as CL-1, was made by mixing 1 g of curcumin extract with 20 mL of PVA solution while it was warm to ensure that the mixture was uniform. Another solution, known as CL-2, was created by mixing 15 mL PVA with 2 g of curcumin extract to achieve homogeneity. Both solutions were prepared and chilled to room temperature. Although less than 1 g and more than 2 g of curcumin extract can be used to make nanofibrous mats, their uses are limited by their low potential and stickiness.

The two prepared solutions were pumped into the machine's pump (TL-Pro-BM, Tong Li Tech, China; model number). The components of the electrospinning system are a high voltage supply (-20 kV and +50 V), a rotary drum collector (diameter: 158 mm, length: 500 mm, 500 r/min), a syringe (30 mL), a heater (0.5 kW), and five (20 gauge) needles. Nanomats were collected on an aluminum foil-wrapped collector drum that was connected to a negative voltage source. Trial and error adjustments were made to the ideal electrospinning conditions, which were ambient conditions of 65% relative humidity and 27°C.

SEM (Scanning Electron Microscope):

At various magnifications, a scanning electron microscope (SU 1510, Hitachi, Japan) was used to measure the orientation of nanofibers as well as their diameter. The diameter of the electrospun fibers was measured from at least five distinct points on the fibrous mats. In order to assess the fiber diameters, 30 fibers were selected as a sample, and each individual diameter was used to measure frequency.

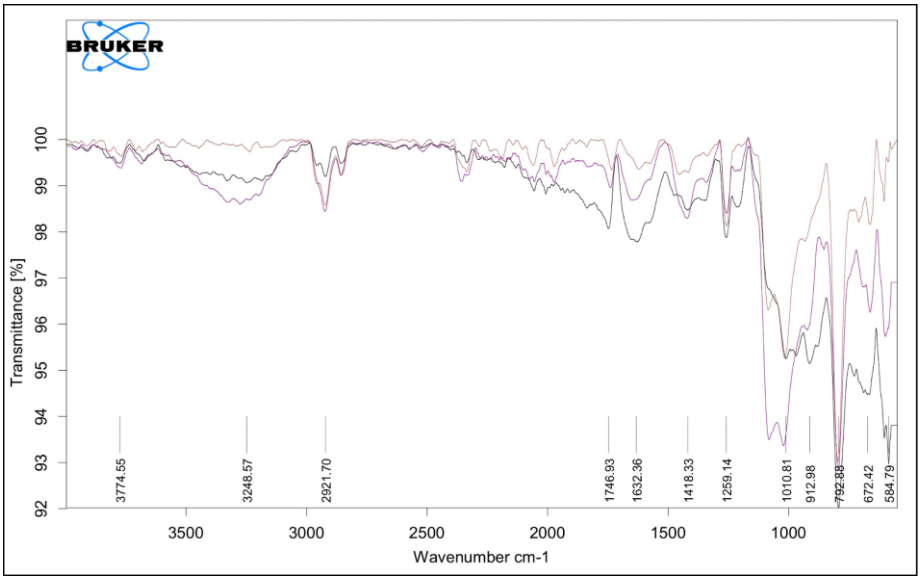
The produced mats' moisture management capabilities were assessed using a moisture management tester (MMT; M290, SDL Atlas, UK) in accordance with AATCC 195-2009's methodology. The above-mentioned standard was used to evaluate the mat's wetting time, absorption rate, maximum wetted radius, spreading speed, cumulative one-way transport capacity (R), and overall moisture management

capacity (OMMC) in order to classify it according to how it interacts with liquid. To analyze the moisture qualities, the test was run using a saline solution containing 0.9% sodium chloride and a 120-s monitoring period.

FTIR Analysis:

Fourier-transform infrared spectroscopy (FTIR; IRPrestige21, Shimadzu Corporation, Japan) was used to analyze the chemical composition of PVA nanofiber, CL-1, and CL-2. The samples' spectra were captured with a resolution of 4 cm1 and a range of 580–4000 cm1.

RESULT



The generated material contains functional groups of PVA, and curcumin extract, as shown in Figure , which was validated by infrared spectroscopy. The finger print region falls within the range of 1250-500 cm1, whilst the functional group region is located in the range of 4000-750 cm1.

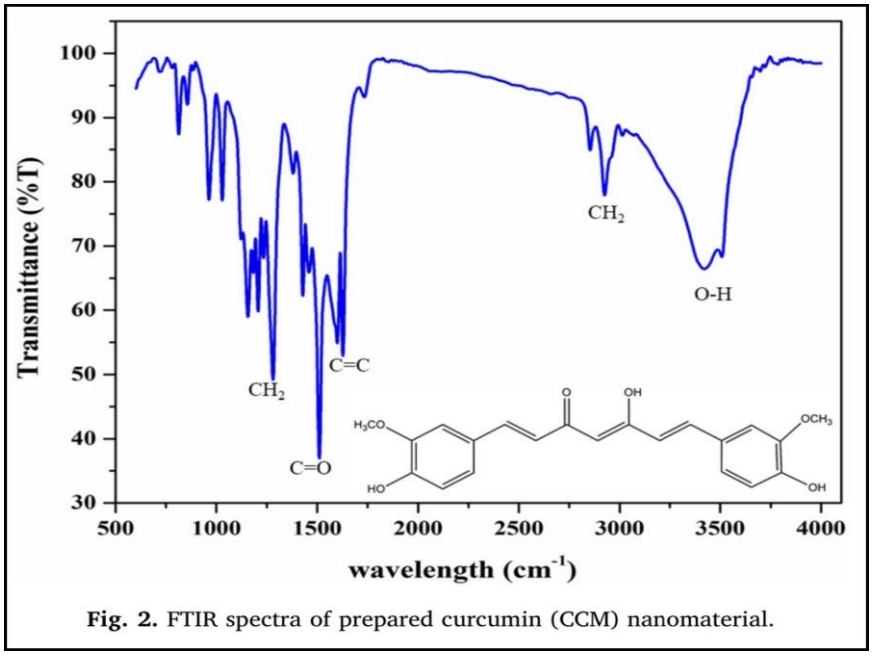
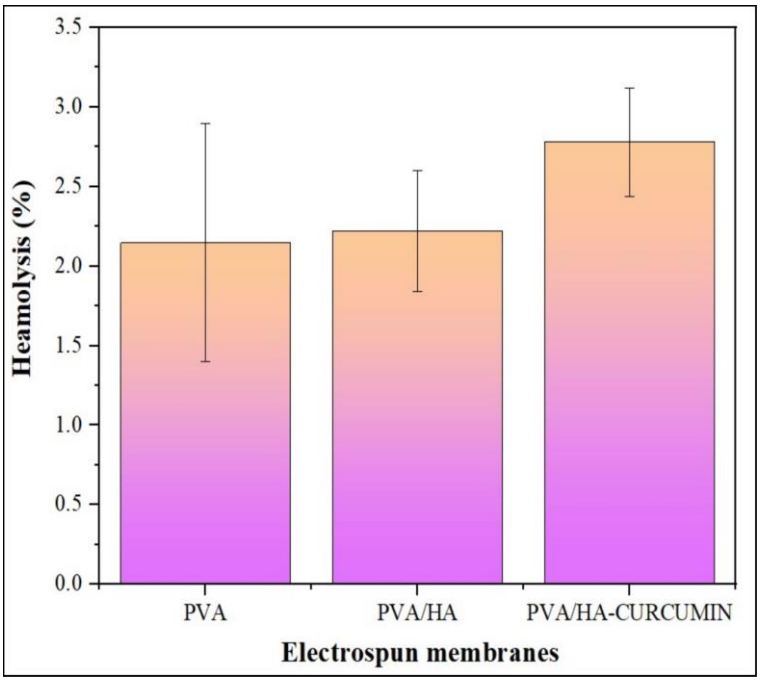


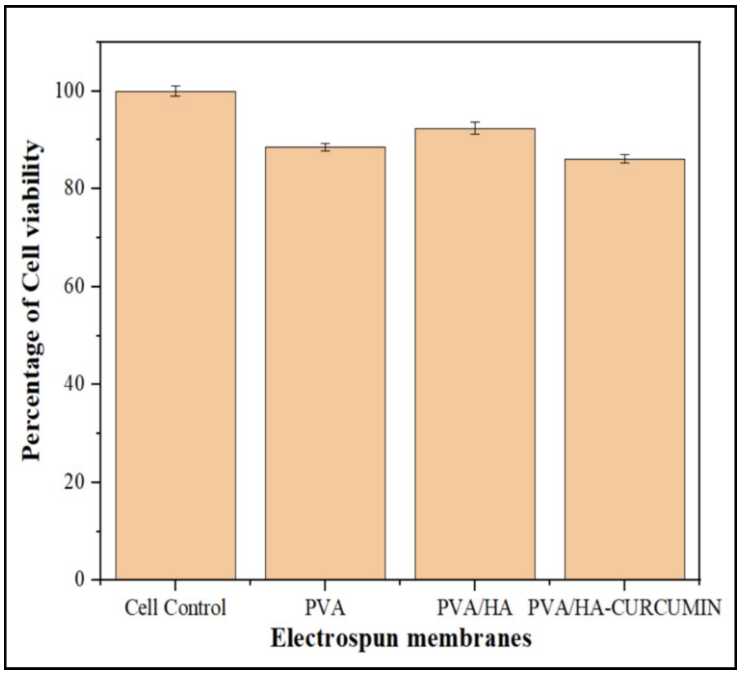
Fig. 2. FTIR spectra of prepared curcumin (CCM) nanomaterial.

ISSN 1462 2815

In addition, the PVA nanofiber showed maxima at 3433 cm-1 (O-H stretching), 2927 cm-1 (C-H stretching). This is consistent with the distinctive PVA peaks identified in other research. The carbonyl group and ethylene group of the curcumincuminextract are present, as evidenced by the band spectra at 1500 cm-1 and 1600-1650 cm-1. The bending vibrations of the -CH bond of the alkene group were shown by the peaks at 725 cm1, 817 cm1, and 967 cm1. Additionally, the ether group in curcumin's C-O stretching correlates to the peak at 1500 cm1. The peak between 1500 and 1250 cm1 revealed the frequency of -OH group -C-O elongation in curcumin.



Percentage of hemolysis is higher for PVA/ha- curcumin fiber. It may result in higher blood loss during the tissue regeneration process. So hemolysis may be a slight disadvantage of this nano fibre synthesised.



ISSN 1462 2815

Percentage of cell viability estimation is an important assay to determine biocompatibility of a synthesized compound. In our research the nanofibers made of PVA/HA - CURCUMIN had a good cell viability rate of 85% which makes us confirm that it is a good biocompatible substance. Higher the biocompatibility of a substance greater is its potential to regenerate tissue.

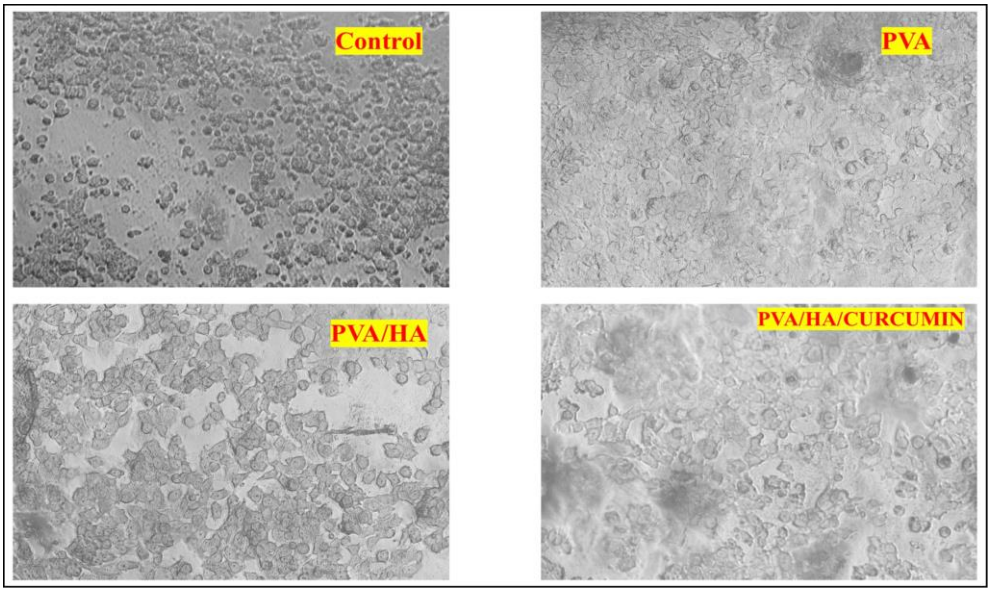


Figure 1: Depicts the Production of Smooth Nanofiber for all Samples with an Average Diameter of 340 nm

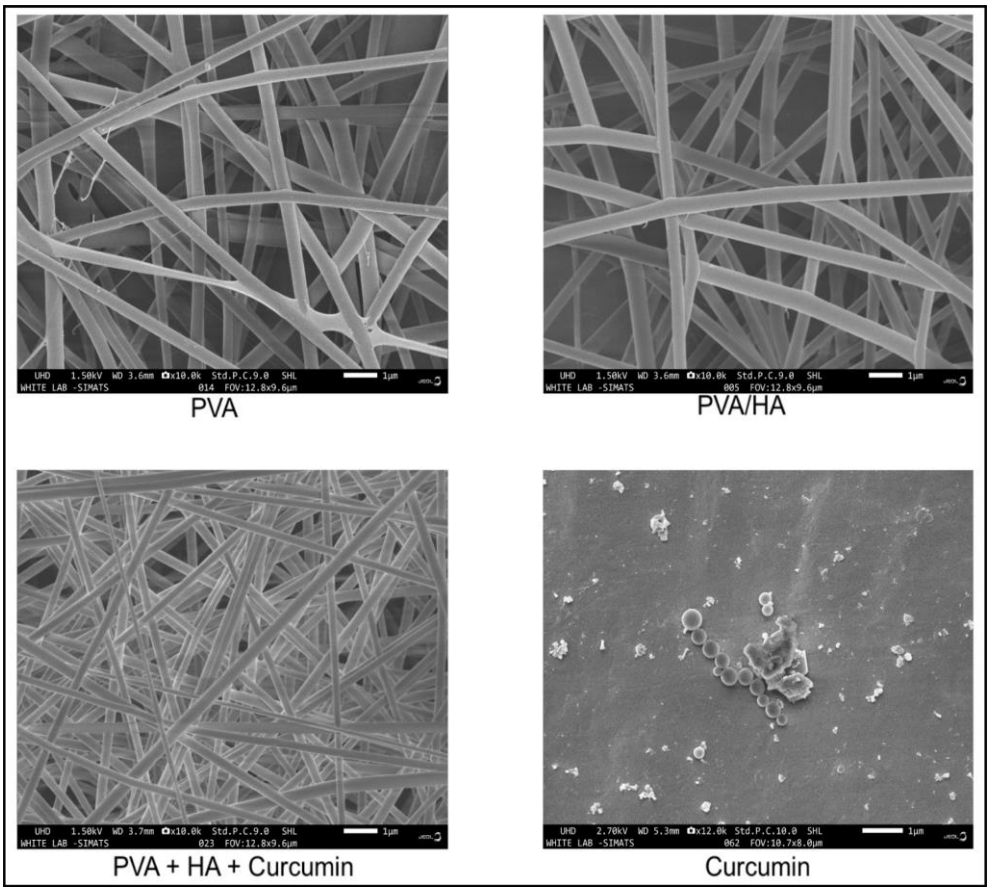


Figure 2: Depicts the Mat-Formation Process

Voltage, pressure, the environment, heater power, and collector distance were taken into account when determining the electrospinning parameters. By using a trial-and-error methodology, the ideal electrospinning settings were discovered at -12.3 kV, +23 kV, 0.45 kW, 1.5 mL per hour, and ambient conditions of 65% relative humidity and 27°C, respectively. When the applied voltage is less than 12 kV, no fiber is created because the surface tension of the solution prevents it from flowing towards the collector. As a result, all samples maintained a voltage differential of greater than 12 kV. However, since collection distance affects fiber diameter, a constant collector distance was kept (15 cm for all samples). The generated samples' scanning electron microscopy (SEM) pictures are displayed in Figures 1 and 2, respectively. Figure 1 depicts the production of smooth nanofiber for all samples with an average diameter of 340 nm and Figure 2 depicts the mat-formation process.

DISCUSSION

The nanofibrous scaffolds have special qualities that make them suited for use as cell and drug delivery systems.(27) The curcumin's structure and features prevent the development of an optimal nonfibrous or fibrous construct for the curcumin's proper delivery for medical applications. (28)Nanofibers have a number of significant benefits over other reported curcumin carriers, including low cost, a simple production procedure, high encapsulation efficiency, appropriate drug loading capacity, multidrug and/or cell delivery, and controlled curcumin release profiles.(29)(30,31)

Additionally, it has been noted that when Cur is added to a spinning solution, the average diameter of the nanofibers decreases, which has an impact on the fiber diameter and morphology.(32)

(33)The mechanical properties of fibrous composites are constrained by bead formation, fiber diameter adjustment, fiber deformation, burst Cur releases, and other factors, which drives researchers to conduct research to develop the optimal Cur nanofibrous integrated scaffold. (33,34)(35)

The substrate features influencing the cellular response in delivery systems include mechanical properties, surface chemistry, and topography, as well as substructures (layers, porosity, interconnectivity, etc.), protein adsorption, wettability, softness, stiffness, and wrinkles.(36) The hydrophobicity and limited bioavailability of Cur, a potentially beneficial natural substance, are two of its key drawbacks. MSC-based therapy, on the other hand, has emerged as a promising therapeutic area in regenerative medicine.(32) To provide a novel framework for numerous regenerative medicine applications, we attached these objects side by side. (37)(38)

In future PVA concentration needs to be raised in order to remove beads from electrospun nanofibers.(39) The ability to produce uniform nanofibers free of beads was restricted because the carbo-pol/PCL copolymer solution led to the development of beads in the electrospun nanofibers.(40)(41) Two approaches in particular stand out as ways to reduce beads in carbopol/PCL nanofibers: high-speed rotary spinning, also known as centrifugal spinning, and electrospinning.

CONCLUSION

The ideal processing conditions for the creation of PVA-curcumin nanofibrous mats filled with curcumin extract have been described in this study. In this case, samples were created using the electrospinning technique at two different mixing ratios, after

which they were characterized. The produced nanofibrous mats were characterized using SEM, MMT, an antibacterial assay, and FTIR. By displaying their distinctive peaks, the FTIR result verified the presence of PVA, and curcumin extract constituents. The curcumin extract -infused PVA nanofibrous mats shown improved moisture management abilities. The generated samples demonstrated the production of inhibition zones of 29 mm and 38 mm due to the antibacterial components of curcumin extract, but no inhibition zone was formed for the same bacterium using PVA nanofiber alone. These characteristics suggest that tissue engineering and possible usage as wound dressing materials for the generated nanomats. There could be a wide range of applications for this multicomponent combination in different technical disciplines.

Name of the Funding Agency:

The present project is funded by

1. Saveetha Institute of Medical and Technical Sciences
2. Saveetha Dental College and Hospitals
3. Saveetha University
4. Kumaran Department Stores

Acknowledgment:

We extend our sincere gratitude to Saveetha Dental College and hospitals for their constant support and successful completion of this work.

Conflict of Interest:

The authors hereby declare that there is no conflict of interest in this study.

Ethical Clearance: Since it is an in vitro study ethical clearance is not needed.

References

1) Ahmed Khan HL, Murthykumar K, Ganapathy D. Genetic Association of the C-C Motif Chemokine Ligand 2 (CCL2) rs1024611 Polymorphism With Periodontitis. Cureus. 2023 Oct;15(10):e46438.

2) Bano R, Brar BK, Kumar S. Comparative Evaluation of Therapeutic Efficacy and Safety of Microneedling Alone Versus Microneedling with Hyaluronic Acid in Post-Acne Scarring. J Cutan Aesthet Surg. 2023 Oct-Dec;16(4):279–85.

3) Romeo F. An Innovative Approach for Nasal Reshaping using Hyaluronic Acid Intradermal Injections. J Cutan Aesthet Surg. 2023 Oct-Dec;16(4):306–11.

4) Yang J, Liu Y, Chen K, Liu M. The hyaluronic acid gel promotes the formation of osteoblasts mineralized nodules and fracture callus by regulating the expression of Runx2 and osteocalcin. Cell Mol Biol . 2023 Dec 31;69(15):136–40.

5) Arora O, Ahmed N, Nallaswamy D, Ganapathy D, Srinivasan M. Denture base materials: An in vitro evaluation of the mechanical and color properties. J Dent. 2024 Apr 22;145:104993.

6) Costa FR, Santos M da S, Martins RA, Costa CB, Hamdan PC, Da Silva MB, et al. The Synergistic Effects of Hyaluronic Acid and Platelet-Rich Plasma for Patellar Chondropathy. Biomedicines [Internet]. 2023 Dec 19;12(1). Available from: http://dx.doi.org/10.3390/biomedicines12010006

7) Venugopalan S, R S, N T, Maiti S. An Analysis of Implant Prosthesis and Its Dynamic Occlusal Contacts. J Long Term Eff Med Implants. 2022;33(1):1–7.

8) de Matos Lourenço L, Colla LA, Ortiz de Noronha MG, Izzo TR, Sigrist R. Square technique-A treatment for cellulite with large size particle hyaluronic acid. Skin Health Dis. 2024 Feb;4(1):e290.

9) Huang Y, Zheng J, Zeng G, Xu H, Lv Y, Liang X, et al. Chitosan-crosslinked polyvinyl alcohol anti-swelling hydrogel designed to prevent abdominal wall adhesion. Mater Today Bio. 2024 Feb;24:100931.

10) Deshmukh M, Venugopalan S, Maiti S, Wadhwani V. A novel technique to detect cover screw location at stage two uncovery surgery over conventional technique - A randomized controlled trial. J Indian Prosthodont Soc. 2024 Jan 1;24(1):46–51.

11) Bercea M, Plugariu IA, Dinu MV, Pelin IM, Lupu A, Bele A, et al. Poly(Vinyl Alcohol)/Bovine Serum Albumin Hybrid Hydrogels with Tunable Mechanical Properties. Polymers [Internet]. 2023 Dec 4;15(23). Available from: http://dx.doi.org/10.3390/polym15234611

12) Ramanathan V, Venugopalan S, Ganapathy D, Ramadoss R, Kumar SM, Kannan RK, et al. Effect of Dietary Amino Acids L-Arginine and Lysine on Implant Osseointegration. J Pharm Bioallied Sci. 2022 Jul;14(Suppl 1):S106–9.

13) Grande-Tovar CD, Castro JI, Tenorio DL, Zapata PA, Florez-López E, Valencia-Llano CH. Chitosan-Polyvinyl Alcohol Nanocomposites for Regenerative Therapy. Polymers [Internet]. 2023 Dec 1;15(23). Available from: http://dx.doi.org/10.3390/polym15234595

14) Ramasamy P, Sekaran S, Ganapathy D. Oral cancer burden in tribal populations residing in India. Oral Oncol. 2024 May;152:106801.

15) Yuvashree CS, Venugopalan S, Nesappan T, Antony SDP. Comparing Closed Tray Implant Impression Techniques Using Snap-On and Impression Analogues on a Clinical Radiographic Scale. J Long Term Eff Med Implants. 2021;31(1):1–6.

16) Maleki H, Doostan M, Khoshnevisan K, Baharifar H, Maleki SA, Fatahi MA. and extracts co-loaded polyvinyl alcohol and chitosan electrospun nanofibers for tackling infection and wound healing promotion. Heliyon. 2024 Jan 15;10(1):e23719.

17) Biţă A, Scorei IR, Bălşeanu TA, Rău G, Ciocîlteu MV, Mogoşanu GD. Zinc-Boron Complex-Based Dietary Supplements for Longevity and Healthy Life. Curr Health Sci J. 2023 Sep 30;49(3):381–7.

18) Chen Y, Qian H, Peng D, Jiang Y, Liu Q, Tan Y, et al. Antimicrobial peptide-modified AIE visual composite wound dressing for promoting rapid healing of infected wounds. Front Bioeng Biotechnol. 2023;11:1338172.

19) Coban SN, Polatoglu I, Eroglu E. Methyl cellulose/okra mucilage composite films, functionalized with Hypericum perforatum oil and gentamicin, as a potential wound dressing. Int J Biol Macromol. 2024 Jan;254(Pt 1):127757.

20) Sivaperumal P, Ganapathy D, Kamala K. Revolutionizing oral cancer treatment: Harnessing the potential of adaptive CARneg T cell therapy. Oral Oncol. 2024 Apr 8;152:106794.

21) Maheshwaran B, Chokkatt JJ, Shenoy A, Ganapathy D, Yadalam PK, Marrapodi MM, et al. Therapeutic evaluation of titanium dioxide nanoparticles based herbal dental varnish derived from rosemary and ginger extracts:A comprehensive investigation into anti-inflammatory and antioxidant properties. Technol Health Care [Internet]. 2024 Feb 3; Available from: http://dx.doi.org/10.3233/THC-231994

22) Kanno Y, Hasegawa O, Kawase-Koga Y. A Novel Dressing Method to Achieve Early Natural Tracheostoma Closure. J Craniofac Surg. 2024;35(1):e44–5.

23) Genesi BP, de Melo Barbosa R, Severino P, Rodas ACD, Yoshida CMP, Mathor MB, et al. Corrigendum to “Aloe vera and copaiba oleoresin-loaded chitosan films for wound dressings: Microbial permeation, cytotoxicity, and in vivo proof of concept” [Int. J. Pharm. 634 (2023) 122648]. Int J Pharm. 2024 Jan 26;123823.

24) Narde J, Ganapathy D, Pandurangan KK. Evaluation of the Success of Autogenous Block Grafting in Atrophic Maxillary and Mandibular Ridges Prior to and After Implant Placement. Cureus. 2024 Feb;16(2):e53829.

25) Boateng J. Therapeutic Dressings and Wound Healing Applications. John Wiley & Sons; 2020. 444 p.

26) Mirzaeei S, Pourfarzi S, Saeedi M, Taghe S, Nokhodchi A. Development of a PVA/PCL/CS-Based Nanofibrous Membrane for Guided Tissue Regeneration and Controlled Delivery of Doxycycline Hydrochloride in Management of Periodontitis: In Vivo Evaluation in Rats. AAPS PharmSciTech. 2024 Jan 30;25(1):27.

27) Revathi D, Dhanraj G, Ashok V. Immune check point inhibitors: A promising therapeutic approach in oral cancer. Oral Oncol. 2022 Sep;132:105977.

28) Agrawal A, Rashmi Kiran E, Deepika S, Kumar P, Kochar D, Ruhi S, et al. Effect of curcumin, betadine and chlorhexidine in gingival wound healing. Bioinformation. 2023 Dec 31;19(12):1153–8.

29) Li Y, Deng X, Tan X, Li Q, Yu Z, Wu W, et al. Protective role of curcumin in disease progression from non-alcoholic fatty liver disease to hepatocellular carcinoma: a meta-analysis. Front Pharmacol. 2024 Jan 19;15:1343193.

30) Selvaraj K, Venkatesan LS, Ganapathy D, Sathishkumar P. Treatment of dental biofilm-forming bacterium Streptococcus mutans using tannic acid-mediated gold nanoparticles. Microb Pathog. 2024 Apr;189:106568.

31) Madasamy S, Ganapathy D, Easwaran M, Baskar V. Fucoidan a sulphated polysaccharide of brown seaweeds: a potential anticancer agent to treat oral cancer. Nat Prod Res. 2024 Feb 10;1–3.

32) Duraisamy R, Ganapathy D, Shanmugam R, Devaraj E, Shenoy A. Assessment of Antimicrobial Activity of Nanocomposites Based on Nano-Hydroxyapatite (HAP), Chitosan, and Vitamin K2. Cureus. 2024 Jan;16(1):e53339.

33) International SC. Retracted: Block Copolymer Nanomicelle-Encapsulated Curcumin Attenuates Cerebral Ischemia Injury and Affects Stem Cell Marker Expression by Inhibiting lncRNA GAS5. Stem Cells Int. 2024 Jan 24;2024:9873984.

34) Sharma J, Panwar D, Bhushan J, Mehta M, Sidhu K, Jhamb S, et al. An evaluation of antibacterial effect of curcumin-loaded chitosan nanoparticle-coated gutta-percha against. J Conserv Dent Endod. 2023 Sep 16;26(5):560–3.

35) Rohatgi N, Ganapathy D, Sathishkumar P. Eradication of Pseudomonas aeruginosa biofilm using quercetin-mediated copper oxide nanoparticles incorporated in the electrospun polycaprolactone nanofibrous scaffold. Microb Pathog. 2023 Dec;185:106453.

36) Ding J, Mei S, Wang K, Cheng W, Sun S, Ni Z, et al. Curcumin modulates oxidative stress to inhibit pyroptosis and improve the inflammatory microenvironment to treat endometriosis. Genes Dis. 2024 May;11(3):101053.

37) Meng Q, Xu M, Chen L, Xu S, Li J, Li Y, et al. Emulsion for stabilizing β-carotene and curcumin prepared directly using a continuous phase of polysaccharide-rich Schizophyllum commune fermentation broth. Int J Biol Macromol. 2024 Jan;254(Pt 1):127730.

38) Rupawat D, Nallaswamy D, Somasundaram J, Ganapathy D, S N, Sekaran S. An Invitro Chewing Simulation Study Comparing the Wear Resistance Behavior of Polyetheretherketone-Layered Composite Crown and Ceramic-Layered Zirconia Crown. Cureus. 2023 Oct;15(10):e46439.

39) Shukri NMM, Duraisamy R, Balasubramaniam A, Ganapathy D. Evaluation of Implant and Prosthesis Survival Rates Based on Crestal Bone Loss. J Long Term Eff Med Implants. 2023;33(2):1–14.

40) Luss AL, Bagrov DV, Yagolovich AV, Kukovyakina EV, Khan II, Pokrovsky VS, et al. Toxicity Evaluation and Controlled-Release of Curcumin-Loaded Amphiphilic Poly-N-vinylpyrrolidone Nanoparticles: In Vitro and In Vivo Models. Pharmaceutics [Internet]. 2023 Dec 19;16(1). Available from: http://dx.doi.org/10.3390/pharmaceutics16010008

41) Ramasubburayan R, Amperayani KR, Varadhi G, Dhanraj G, Athista M, Mahapatra S, et al. Unraveling bioactive metabolites of mangroves as putative inhibitors of SARS-CoV-2 Mpro and RBD proteins: molecular dynamics and ADMET analysis. J Biomol Struct Dyn. 2023 Oct 28;1–10.