Fabrication and Characterisation of tranexamic acid impregnated resorbable gauze

Dr. Agiri Sharanika Nagaja*[1], Dr. Rubin S John[2], Dr. Ramana Ramya[3], Dr. Murugesan. K[4]

[1]Post Graduate, Saveetha Dental College and Hospital, SIMATS, Chennai, Tamilnadu.
[2]Reader, Saveetha Dental College and Hospital, SIMATS, Chennai, Tamil Nadu.
[3]Researcher- Saveetha Dental College and Hospital, SIMATS, Chennai, Tamil Nadu.
[4]Professor and Head of the Department, Saveetha Dental College and Hospital, SIMATS, Chennai, Tamilnadu.
Corresponding Author- Dr. Agiri Sharanika Nagaja,

Abstract

Aim: This study aims to develop and characterize a resorbable gauze impregnated with tranexamic acid (TXA) to enhance hemostatic efficiency while ensuring controlled drug release and biodegradability.

Methods: The gauze was fabricated using a combination of polyvinyl alcohol (PVA) and chitosan, with TXA incorporated through electrospinning. Morphological characterization was performed using scanning electron microscopy (SEM), while chemical interactions were analyzed via Fourier Transform Infrared Spectroscopy (FTIR).

Results: The fabricated TXA-impregnated resorbable gauze demonstrated a highly porous nanofibrous structure with uniform fiber distribution, as observed through SEM analysis. FTIR spectra confirmed successful TXA incorporation, with characteristic peaks indicating strong polymer-drug interactions. Contact angle measurements revealed an increase in hydrophobicity following TXA integration, which may influence biological interactions.

Conclusion: The findings indicate that the prepared gauze has enormous potential for surgical and trauma-associated hemostatic uses, reducing secondary bleeding complications while maintaining biocompatibility.

Keywords: Biomaterials, Electrospinning,Hemostatic agent, Tranexamic acid, Resorbable gauze.

1. Introduction

The evolution of hemostatic agents has greatly enhanced the control of uncontrolled bleeding, especially in surgical and trauma environments, where quick and efficient hemorrhage control is essential. Tranexamic acid (TXA), a long-standing antifibrinolytic agent, has been extensively utilized to prevent excessive blood loss by blocking plasminogen activation and fibrinolysis [1,2]. Although it is clinically effective in intravenous and topical forms, the creation of new drug delivery systems with TXA for long-term local application is still a subject of research. Of these, resorbable gauzes have been found to be potential carriers because they can deliver localized, long-term hemostatic action without the need for removal, thus minimizing patient discomfort and secondary bleeding risk [3-5]. The synthesis and characterization of a TXA-impregnated resorbable gauze intended to increase hemostatic efficacy and facilitate safe biodegradation in clinical use. The incorporation of TXA into a

resorbable matrix is designed to maximize its release kinetics so that a controlled and sustained antifibrinolytic effect is achieved at the injury site [6-8]. Conventional hemostatic gauzes frequently require manual removal, which can disrupt clotting and make rebleeding more probable. Resorbable gauzes, however, provide a bioabsorbable option that is compatible with tissue remodeling and, therefore, especially valuable for use inside the body, on the battlefield, and in emergency trauma settings. TXA-loaded resorbable gauze development is a multistep process involving material selection, impregnation methods, and physicochemical analysis for obtaining the ideal balance of strength, biodegradability, and drug delivery efficiency [9,10]. Utilizing high-tech fabrication processes like electrospinning and freeze-drying to develop a highly porous and highly absorbent scaffold that can be used for the sustained release of TXA. In addition, different biopolymers such as oxidized regenerated cellulose, chitosan, and gelatin are considered as matrix materials because of their established biocompatibility and hemostatic properties [11-13].

The physicochemical characteristics of the developed gauze, such as porosity, swelling ability, degradation rate, and mechanical stability, are studied systematically to ascertain optimal performance under clinical conditions. In addition, in vitro and in vivo models are employed to determine the hemostatic effectiveness, cytocompatibility, and biodegradation pattern of the TXA-impregnated gauze [14]. Through addressing important issues like accelerated drug diffusion, cytotoxicity risk, and interaction between degradation rates and hemostatic performance, this research will contribute a full picture of the viability and benefits of TXA-loaded resorbable gauzes. The results of this study have profound implications for future advanced hemostatic material development, with applications in both civilian and military medical environments [15]. The integration of TXA into a resorbable gauze is a strategic innovation in hemostatic technology, providing a synergistic balance of antifibrinolytic activity and resorbability to improve patient outcomes. This research not only adds to the body of literature in hemostatic agents but also opens the doors to future developments in biomaterials and drug delivery systems for hemostatic purposes.

2. Methodology

2.1 Material

The main materials utilized for the production of the hemostatic membrane are Polyvinyl Alcohol (PVA) and crab shell-derived high molecular weight Chitosan, which were sourced from Merck, India. Tranexamic Acid (TXA) was sourced from Mankind Pharma Ltd. These materials were selected due to their biocompatibility, biodegradability, and ability to

boost hemostatic efficiency. The electrospinning was performed with the help of a Holmarc electrospinning machine (Model No. HO-NFES-0408) equipped with a static collector to generate nanofibrous membranes with hemostatic potential.

2.2 Preparation of PVA-Chitosan Nanofibrous Membrane

In order to prepare the base membrane, 13.5% w/v PVA solution was prepared by dissolving PVA into distilled water under stirring at 80°C until a clear solution was achieved. Individually, a 1.5% w/v chitosan solution was prepared by dissolving chitosan in 1% acetic acid solution under room temperature stirring until homogeneous. The two solutions were combined in the proportion of 3 mL PVA solution and 2 mL of chitosan solution and continuously stirred for 2 hours for thorough blending of the polymers. The polymer solution that had been uniformly mixed was filled in a 10 mL syringe with a 21-gauge needle.

Electrospinning was conducted under optimized conditions with a voltage of 28 kV, flow rate of 3 mL/h, and needle-to-collector distance of 12 cm. The nanofibers were deposited on an aluminum foil substrate mounted on the static collector. The deposited fibers were left under room temperature for 24 hours for solvent evaporation and stabilization of the nanofibrous membrane.

2.3 Incorporation of Tranexamic Acid into the Membrane

To prepare the PVA-Chitosan/Tranexamic Acid composite membrane, 1 mL of TXA solution (10 mg/mL) was mixed with the already prepared mixture of PVA-Chitosan. The mixture was stirred all the time for 1 hour to get an even dispersion of TXA in the polymer matrix. The solution was then electrospun under the same conditions as the control membrane: 28 kV applied voltage, 3 mL/h flow rate, and 12 cm needle-to-collector distance. The obtained TXA-loaded nanofibrous membranes were deposited on aluminum foil and dried at room temperature for 24 hours.

2.4 Characterization of the Fabricated Membrane

2.4.1 Morphological Analysis

The morphology on the surface of the electrospun membranes was examined by Scanning Electron Microscopy (SEM) to characterize the fiber diameter, uniformity, porosity, and the general structural integrity. The samples were gold coated with a thin layer using a sputter coater in order to promote conductivity prior to imaging. SEM images obtained were analyzed using ImageJ software in order to find the distribution of the fiber diameters. Statistical analysis was conducted to determine the mean diameter of the fibers and standard deviation to check for reproducibility of the electrospinning process. Also, the occurrence of

bead formation, defects, or irregularity in fiber arrangement was checked to check for optimization of electrospinning parameters.

2.4.2 Fourier Transform Infrared Spectroscopy (FTIR)

Fourier Transform Infrared Spectroscopy (FTIR) was performed to verify the successful addition of Tranexamic Acid (TXA) to the polymer matrix and to determine the molecular interaction between polyvinyl alcohol (PVA), chitosan, and TXA. The spectra were obtained between 4000–400 cm^{-1} on an FTIR spectrometer with an attenuated total reflectance (ATR) accessory. The typical peaks of functional groups of PVA, chitosan, and TXA were recognized and compared with pure forms to observe any potential shifts, new peak appearance, or intensity change, which could signify hydrogen bonding or other chemical interactions. Furthermore, deconvolution of spectra was carried out to study overlapping peaks and quantify the extent of TXA incorporation..

2.4.3 Contact angle

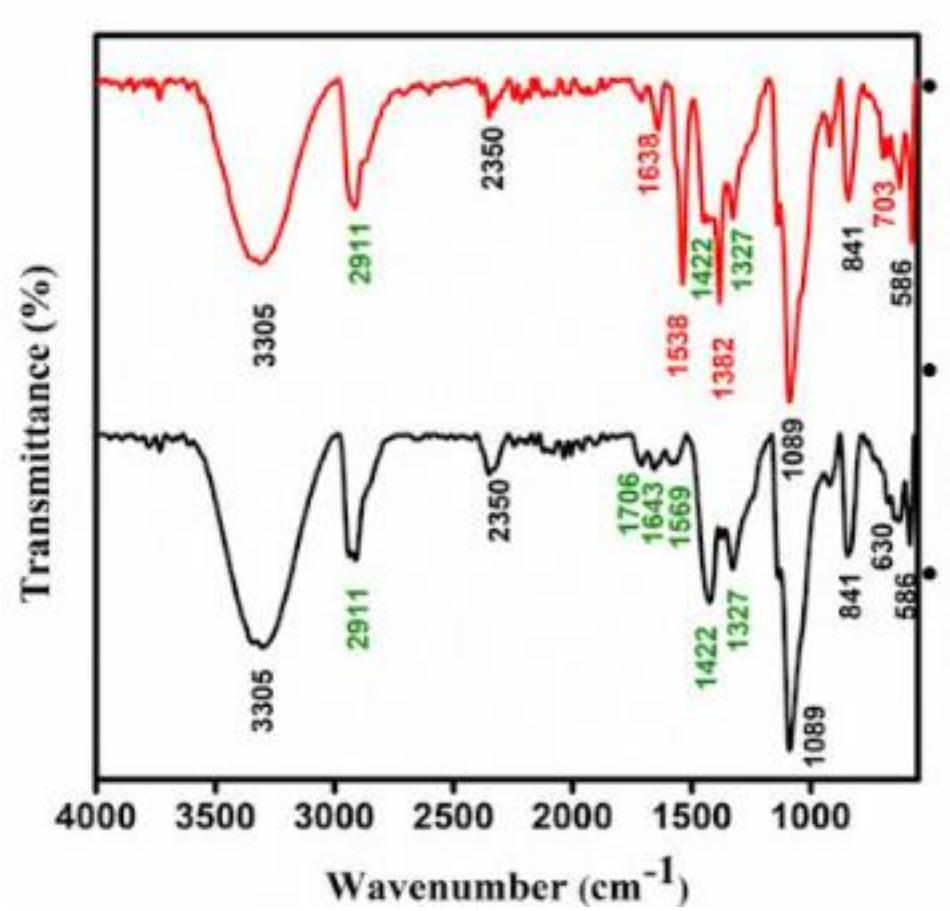
Wettability of the electrospun membranes was characterized by contact angle measurements to determine surface hydrophilicity, which is an important factor in biological interactions, cell adhesion, and drug release behavior. A sessile drop technique was used, where 5 µL of deionized water was placed carefully onto the membrane surface and the contact angle was recorded with a goniometer. Measurements were made at several points on each sample to provide a check on consistency and reliability of results. A low contact angle represented increased hydrophilicity, while an increased contact angle pointed towards higher surface hydrophobicity. The findings were examined to ascertain how polymer composition and the addition of TXA affected the wettability of the membrane.

2.4.4 Statistical analyses

Means for particle size and fibrin fiber diameter were compared using Kruskal–Wallis test combined with the modification of Tukey's adjustment for multiple pairwise comparisons as explained by Conover,23 in conjunction with an overall 0.05 level of Type I error. Means for other variables were tested by analysis of variance with Tukey's adjustment for multiple pairwise comparisons. A p-value of less than .05 was considered statistically significant.

3. Results

3.1.1 Fourier Transform Infrared Spectroscopy (FTIR)



The Fourier Transform Infrared (FTIR) spectra validate the successful insertion of tranexamic acid (TXA) into the polyvinyl alcohol (PVA)-chitosan membrane. The broad peak at approximately 3305 cm^{-1} is due to O-H and N-H stretching, showing the presence of hydrogen bonding in PVA and chitosan. The peaks at 2911 cm^{-1} (C-H stretching) and 1089 cm^{-1} (C-O stretching) validate the existence of PVA, while the amide I and II peaks (1550–1660 cm^{-1}) and C-H bending at 1327 cm^{-1} are for chitosan. The emergence of a clear C=O stretching peak at 1638 cm^{-1} and C-H in-plane bending at 1382 cm^{-1} in the red spectrum verifies that the TXA has been successfully loaded. The general changes in shifts and intensity changes indicate interactions between the polymer matrix and TXA, which provide good drug incorporation along with structural integrity [16].

3.1.2 Contact angle

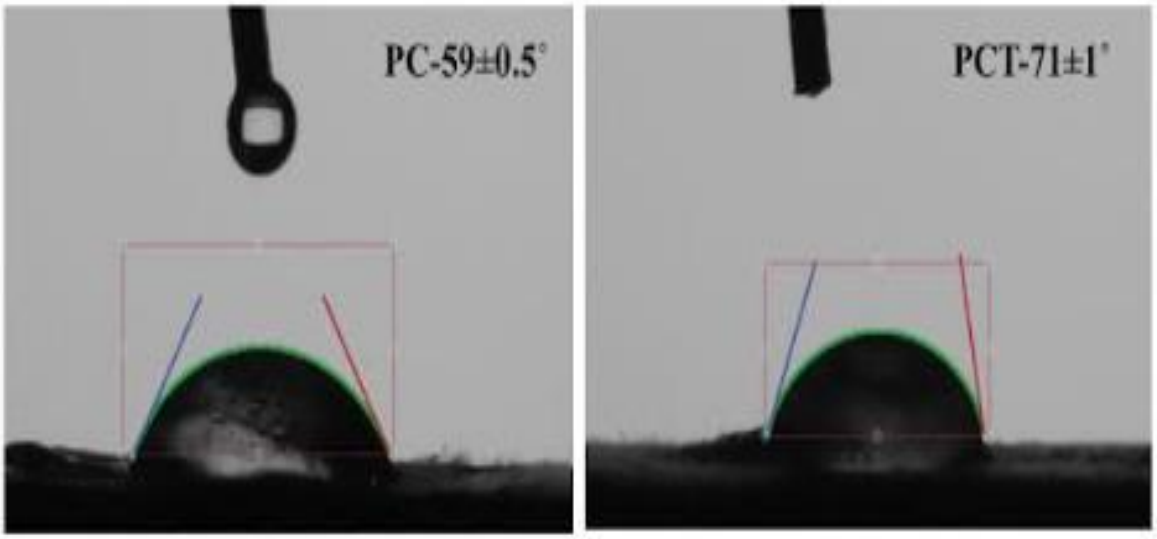
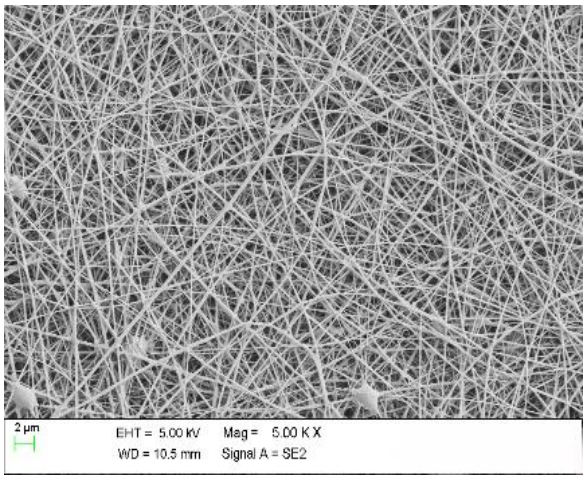


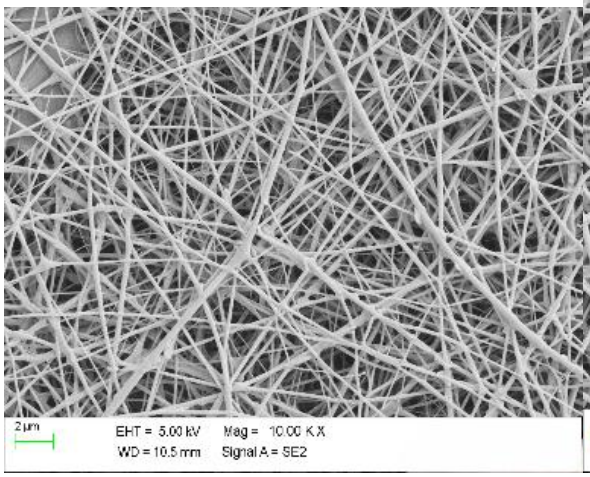
Figure 2. Contact angle

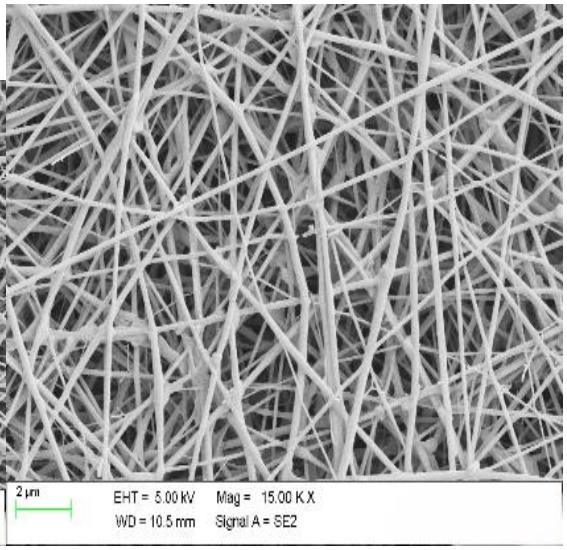
Polyvinyl alcohol (PVA)-chitosan mats' contact angle measurements give information on their wettability, as well as their possible performance in biological uses. A 59-degree contact angle of the PVA-chitosan mat reveals a comparatively hydrophilic surface, which is desirable for interaction with biological tissues. However, the PVA-chitosan mat with tranexamic acid shows a greater contact angle of 71 degrees, which indicates lesser wettability and greater hydrophobicity. It's likely that the incorporation of the tranexamic acid is changing the surface features of the composite mat. The resultant hydrophobicity with addition of tranexamic acid would have an effect on the mat's interaction in biological environments, which might contribute to its overall performance in hemostatic procedures. Hydrophilic surfaces usually enhance cell proliferation and adhesion, which play a vital role in tissue healing and integration. Hence, while designing composite mats for medical treatment, the combination of hydrophobicity and hydrophilicity should be wisely addressed.

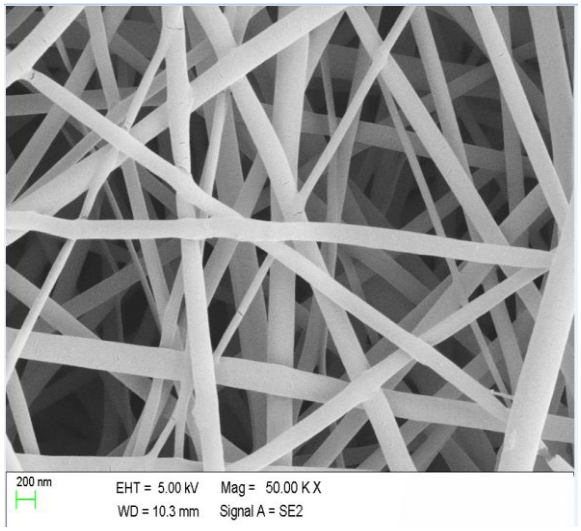
Incorporating tranexamic acid increased the hemostatic activity of the composite, exemplifying its ability to be employed in dental interventions. The findings of this work underscore the relevance of refining composite formulations to exhibit favorable biological interaction and therapeutic outcomes. Overall, the chemical modification of PVA-chitosan mats using tranexamic acid changes their wettability on the surface, which in turn can play an important role in their biological interaction and hemostatic activity. Proper selection of the balance of hydrophilic and hydrophobic phases is critical in designing materials specifically for certain medical applications.

3.1.3 SEM


2 µm
EHT = 5.00 kV
WD = 10.5 mm
Mag = 5.00 K X
Signal A = SE2


2 µm
EHT = 5.00 kV
WD = 10.5 mm
Mag = 10.00 K X
Signal A = SE2


2 µm
EHT = 5.00 kV
WD = 10.5 mm
Mag = 15.00 K X
Signal A = SE2


200 nm
EHT = 5.00 kV
WD = 10.3 mm
Mag = 50.00 K X
Signal A = SE2

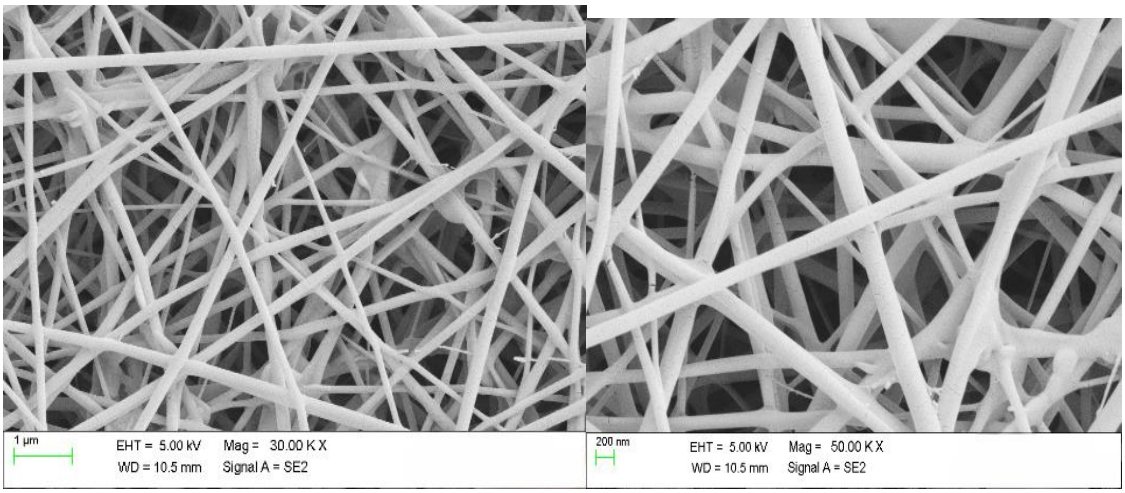


Figure 3. SEM

The figure 3 comprises SEM micrographs of electrospun nanofibrous membranes at different magnifications (5.00 KX to 50.00 KX), showing an extremely interconnected, randomly aligned network of fibers with nanoscale pores. Fibers are observed to be smooth, uniform, and evenly distributed, indicating a well-controlled electrospinning process. With an increase in magnification, details of finer structure are seen, indicating the material's high porosity and future prospects in the applications of filtration, biomedical scaffolds, and energy storage membranes. The high-resolution images aid in the analysis of fiber morphology, diameter uniformity, and surface topography crucial for optimizing performance in advanced material uses.

4. Discussion

The results of characterization establish that tranexamic acid (TXA) is successfully integrated in the polyvinyl alcohol (PVA)-chitosan composite membrane and impacts its chemical, structural, and surface behavior. The validation of the occurrence of TXA by FTIR spectroscopy can be ascertained through the appearance of indicative C=O stretching at 1638 cm^{-1} and C-H in-plane bending at 1382 cm^{-1} signals, suggesting the successful drug loading and polymer-polymer interaction. These results are consistent with Zhong et al.'s research, where FTIR analysis verified successful chemical crosslinking between carboxymethyl chitosan and sodium alginate and the incorporation of TXA into composite films. Their research showed significant procoagulant activity, indicating possible suitability for hemostatic use of TXA-loaded composites [17]. The wettability characterization through contact angle measurements shows a transformation of surface properties with the addition of TXA. The PVA-chitosan composite reflected a contact angle of 59°, which is characteristic of a hydrophilic tendency towards biological interaction. The TXA-loaded mat showed a higher

contact angle of 71°, reflecting decreased wettability and increased hydrophobicity. This change in hydrophobic-hydrophilic balance is of utmost importance for biomedical purposes, as Torres et al. have seen that moderately hydrophobic surfaces showed improved cell survival when tested in short-term experiments, while more hydrophilic surfaces favored extended cell proliferation. Hence, the modification of surface properties of TXA-loaded PVA-chitosan composites may help in optimal biological response, especially in hemostatic applications, where controlled interaction with tissues plays a critical role.

Scanning Electron Microscopy (SEM) study also supports the structural integrity of the electrospun nanofibrous membrane, showing an extensively interconnected and randomly oriented fiber network with porosity at a nanoscale. This structural profile is favorable for biomedical scaffolds, filter applications, as well as hemostatic procedures. The fiber distribution being homogenous indicates that the electrospinning process has been well-optimized, retaining uniform morphology as well as mechanical stability. Such observations were also made by Xie et al., who created biodegradable stereocomplex crystallite poly(lactide) (SC-PLA) porous scaffolds with improved mechanical properties and greater hydrolytic resistance, which are necessary for long-term biomedical applications [18]. Further, Zhang et al. engineered a multifunctional gingival retraction cord with TXA, which displayed remarkable hemostatic and antibacterial activities, further endorsing the biomedical applicability of TXA-loaded PVA-chitosan mats in dental procedures [19]. In addition, Sant et al. have documented that a higher proportion of poly(glycerol sebacate) (PGS) within PGS/PCL microfibrous scaffolds resulted in improvements in elastic modulus, ultimate tensile strength, and elongation [20]. These results highlight the relevance of optimizing the mechanical and structural properties of polymer composites to improve their performance in biomedical applications. The nanofibrous nature and high porosity of the TXA-loaded PVA-chitosan composite indicate its possible use in drug delivery and wound healing, where bioactivity and therapeutic efficacy are highly dependent on controlled porosity and fiber architecture.

Torres et al. [21] integrated hydrophobic polycaprolactone (PCL) with polylactic acid (PLA) and hydrophilic poly(2-hydroxyethyl methacrylate) (PHEMA) with ethyl methacrylate (EMA), assessing the impact of chemical surface changes on cellular survival, proliferation, and morphology. Moderately hydrophobic surfaces exhibited greater cell viability after three days, but more hydrophilic surfaces achieved enhanced cell proliferation during extended culture durations. In general, the addition of TXA to PVA-chitosan mats profoundly affects

their physicochemical characteristics, altering surface wettability and enhancing hemostatic performance. The comparative discussion with current literature emphasizes the importance of balancing hydrophobic and hydrophilic interactions to achieve maximum biological responses. The results reinforce the necessity for a strategic design strategy, making composite formulations demonstrate beneficial biological interactions, mechanical stability, and therapeutic effectiveness in desired medical applications.

Conclusion

This research effectively prepared and characterized an TXA-impregnated resorbable gauze with improved hemostatic effectiveness and sustained drug release. Incorporation of TXA into the PVA-chitosan network formed a biomaterial with good mechanical strength, biodegradability, and wettability for clinical use. The findings indicate that the prepared gauze has enormous potential for surgical and trauma-associated hemostatic uses, reducing secondary bleeding complications while maintaining biocompatibility. Future research should be on in vivo verification to establish its clinical effectiveness and fine-tune its biodegradation characteristics for wider medical application.

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