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Comparative Analysis of Thickness versus Antimicrobial Activity on Coating Methods and Characterization of Chitosan-PVA Coated Polyester Nonwoven for Wound Dressing

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Abstract:
This paper presents the comparative analysis of coating methods and characterization of Chitosan-PVA coated polyester nonwoven for wound dressing application. The fabrics were prepared using three coating methods: padding, screen, and blade coating, with varying polymer concentrations. The coated fabrics were characterized by physical and mechanical testing, scanning electron microscopy (SEM), Fourier transform infrared (FTIR) spectroscopy, antimicrobial testing according to ISO 20645, and in vivo acute oral toxicity evaluation according to ISO 10993-11. The results indicate that the coating method significantly influences the fabric properties, with the blade coating method resulting in the most favorable overall performance. Specifically, this method produced fabrics with superior swelling capacity, enhanced breaking strength, and strong antimicrobial activity compared to the other techniques. SEM analysis reveals a uniform and continuous surface morphology, while FTIR confirms the successful integration of the coating through intermolecular hydrogen bonding. Furthermore, the in vivo toxicity test confirms that the selected samples are non-toxic and biocompatible, with no observable clinical signs of toxicity or mortality during the experimental period.

Keywords: coating methods, Chitosan-PVA coated polyester nonwoven, characterization, wound dressing application

1. Introduction

Among the various coating techniques available for textile finishing, three methods are particularly relevant for applying functional coatings onto fabric surfaces: padding, screen coating, and doctor blade coating. The padding method involves immersing the fabric in the coating solution followed by squeezing through nip rollers to remove excess solution, allowing deep penetration of the coating into the fabric structure [1-5].

The screen coating method, similar to screen printing, involves forcing the coating paste through a mesh screen onto the fabric surface, producing a surface-deposited coating with minimal penetration. The doctor blade method involves spreading the coating solution onto a flat fabric surface using a doctor blade, with coating thickness controlled by the gap between the blade and the substrate. Each method offers distinct advantages and limitations, and the selection of an appropriate method depends on the desired coating properties and application requirements [6-10].

The development of antimicrobial textile materials for wound dressing applications requires an effective coating method that can uniformly deposit functional polymers onto fabric surfaces. While chitosan/PVA blends have been extensively studied as films and hydrogels, their application as coatings on polyester nonwoven substrates using different coating methods remains relatively unexplored. Previous studies have primarily focused on chitosan/PVA films prepared by solvent casting, with limited attention to the systematic comparison of multiple coating techniques and characterization of the resulting antimicrobial properties on nonwoven substrates [11-13].

Firstly, a suitable fabric is selected for antimicrobial finishing treatment based on the specific requirements of wound dressing applications, with particular attention to its potential as a wound dressing material. The polyester nonwoven fabric is chosen due to its favorable properties, including high porosity, breathability, mechanical strength, and suitability for medical and hygienic applications. Secondly, the fabric analysis tests are carried out according to the respective ASTM standards to determine its physical properties. Thirdly, the selected fabric is pretreated with a 2% (w/v) NaOH solution at 50°C for 15 minutes to enhance hydrophilicity and coating adhesion. Then, the pretreated fabric is coated with a chitosan-PVA blend solution using three different coating methods: padding, screen coating, and doctor blade coating. After that, the coated fabric samples are tested and analyzed for physical, mechanical, antimicrobial, and in vivo toxicity properties required for potential wound dressing applications. Finally, the test results obtained are compared and discussed to determine the optimal coating method and formulation.

2. Evaluation of Antimicrobial Activity

The antimicrobial activity of the fabricated Cs/PVA dressings was evaluated at the Pharmaceutical Research Department, Ministry of Industry and Development of Micro, Small and Medium Enterprises, Yangon, Myanmar. The test was conducted to assess the ability of the coated fabrics to inhibit the growth of selected microorganisms.

The antimicrobial activity of the coated fabrics was evaluated using the agar diffusion plate method in accordance with the procedure of ISO 20645. The test microorganisms included Staphylococcus aureus (Gram-positive bacterium), Escherichia coli (Gram-negative bacterium), and Candida albicans (fungus). Circular fabric specimens measuring 10 mm (1 cm) in diameter were placed on agar plates inoculated with the respective test microorganisms. The plates were incubated at the temperature of 37°C for 24 hours, and the inhibition zones surrounding the specimens were assessed and measured in millimetres (mm). According to ISO 20645, an inhibition zone of ≤ 16 mm was classified as Resistant (+), 17.2 mm = Intermediate (++), and ≥ 21 mm = Susceptible (+++). These results were used to compare the antimicrobial performance of the coated fabric samples.

3. In Vivo Toxicity Test (Acute Oral Systemic Toxicity)

The acute oral systemic toxicity test of the fabricated Cs/PVA composite dressings was conducted at Myanmar Pharmaceutical Factory (Insein), Yangon. The potential acute systemic toxicity of Cs/PVA coated polyester nonwoven samples was evaluated using an animal testing protocol based on ISO 10993-11.

Healthy adult Swiss albino mice weighing 20 g were assigned to seven groups, with three animals per group, as specified in the approved study protocol. The groups comprised a control group receiving sterile saline and six treatment groups receiving extracts prepared from selected coated fabric specimens:

S31 and S32 for the padding method, P31 and P32 for the screen coating method, and K31 and K32 for the knife/blade coating method. The selected specimens, representing higher polymer concentration formulations for each coating method, were used for the toxicity evaluation to minimize the number of animals used in this study, in accordance with the 3Rs principle (Reduction) for ethical animal testing.

The fabric specimens were prepared and extracted using sterile saline (0.9% NaCl) at a specimen to extraction medium ratio of 0.1 g/mL for 24 hours at 37°C, in accordance with the approved extraction procedure. The extracts were administered according to the approved study protocol. The extracts were administered according to the approved study protocol. Throughout the 14-day observation period, the animals were closely monitored daily for mortality, behavioural changes, and other clinical signs of adverse effects. Specifically, the body weight of each mouse was measured and recorded on the initial day (Day 1) and subsequently once a week (Days 7 and 14) using an analytical balance to assess potential physiological stress or systemic toxicity. At the end of the study, the animals were handled in accordance with the approved procedure, and the major organs, including the liver, kidneys, heart, and lungs, were examined macroscopically for any visible abnormalities. The physical condition of the mice during the extract administration (Day 1) and their healthy physical condition at the end of the 14-day observation period were illustrated in next section.

4. Comparative Analysis

4.1 Comparative Analysis of Thickness on Coating Methods

According to the significance test results, the coating method has a significant effect on fabric thickness. Additionally, the main effects of chitosan and PVA are also statistically significant.

When comparing the three coating methods, the blade coating method results in the lowest thickness values (ranging from 0.0795 mm to 0.0895 mm), while the screen coating method produces the highest thickness values (ranging from 0.1005 mm to 0.1140 mm). The padding method results in intermediate thickness values (ranging from 0.0985 mm to 0.1060 mm).

Among all the samples tested across the three methods, P_{32} (screen coating, 2.5% Chitosan, 2% PVA) exhibits the highest thickness (0.1140 mm). This is significantly higher than that of the best samples from the padding method (S_{32}, 0.1060 mm) and the blade coating method (K_{32}, 0.0895 mm).

The blade coating method typically results in a thinner film because the blade shears off excess coating solution, leaving only a thin layer on the fabric surface. In contrast, the screen coating method allows for a thicker paste to be deposited through the mesh, resulting in a higher wet pick-up and a thicker final film. As confirmed by the viscosity data, the screen coating formulations have higher solid content, which, upon drying, results in a thicker polymeric layer compared to the blade coating method.

The SEM images confirm that the screen coating covers the fiber surfaces and
partially fills the inter-fiber spaces. For sample P_{32}, the high solid content creates a thick, continuous paste that bridges the fibers and physically adds bulk to the fabric structure. This dense and continuous coating layer is directly responsible for the highest thickness observed.

The FTIR analysis reveals that the internal hydrogen bonding within the Cs/PVA blend creates a highly cohesive and rigid polymer network. This chemically stabilized network solidifies into a thicker, more uniform film on the fiber surfaces and within the fabric interstices. Therefore, the strong chemical interactions are directly responsible for maintaining the structural integrity and thickness of the coating layer.

For wound dressing applications, a moderate thickness is desirable to provide adequate exudate absorption and mechanical protection without being too bulky. Based on the overall results, P_{32} is considered the most suitable sample in terms of thickness. Its high thickness (0.1140 mm) provides better exudate absorption capacity and mechanical protection for the wound bed. While S_{32} (Padding) also shows good thickness, the higher thickness of sample P_{32}, combined with its high weight and swelling capacity, makes it the optimal sample for further development in wound dressing applications.

4.2 Comparative Analysis of Antimicrobial Activity on Coating Methods

When comparing the three coating methods, the blade coating method results in the strongest antibacterial activity, as indicated by the uniform (++) results in Table 4.10. The screen coating method and padding method also show positive (+) results, but the blade coating method exhibits a more pronounced inhibition.

Among all the samples tested on the three methods, K_{32} (blade coating, 2.5% chitosan, 2% PVA) exhibits the strongest antibacterial activity (++). This is notably higher than the best samples from the padding method (S_{32}, +) and the screen coating method (P_{32}, +).

The superior antibacterial activity of the blade-coated samples (particularly K_{32}) is attributed to the specific structural and chemical characteristics of the film formed by this method.

The blade coating method produces a thinner but denser film that adheres closely to the fibers. The SEM images confirm that K_{32} has a continuous and crack-free coating layer. This morphology ensures maximum contact between the active agent of chitosan and the bacteria, while also providing a larger effective surface area for antibacterial action.

The FTIR results confirm the presence of amine groups ($-NH_2$) from chitosan, which are responsible for disrupting bacterial cell membranes by interacting with their negatively charged surfaces.

The strong intermolecular hydrogen bonding confirmed by FTIR anchors the chitosan firmly within the coating layer. This chemical stabilization ensures that a high concentration of active amine groups remains exposed and available on the surface to interact with and neutralize bacteria upon contact.

For wound dressing applications, strong antibacterial activity is essential to prevent infection and promote healing. Based on the overall results, K_{32} is considered the most suitable sample in terms of antibacterial activity. Its strong antibacterial effect against S. aureus, C. albicans, and E. coli ensures that the dressing can provide effective protection against microbial contamination.

While P_{32} and S_{32} also show good antibacterial activity, the superior antimicrobial efficacy of K_{32}, combined with its high weight and thickness, makes it the optimal sample for further development in wound dressing applications.

5. Results on *in vivo toxicity* on coating methods

The in vivo acute oral toxicity results demonstrate a uniform safety profile on all tested formulations and coating methods. As shown in Table 4.11, all animals in the seven groups survive throughout the testing period. No observable clinical signs of toxicity, including behavioral changes, weight loss, or mortality, are recorded during the 24-hour and 14-day observation periods.

Furthermore, macroscopic examinations of the major organs reveal no abnormalities. The photographic evidence in Figure.1 and Figure.2 visually confirms the healthy physical condition of the mice on Day 1 and Day 14.

Based on the toxicity test, these results are fully consistent with the required safety standards. The absence of observable toxic effects across the padding, screen, and knife coating methods indicates that neither the Cs/PVA coating formulations nor the different coating processes produce detectable acute toxic effects under the conditions of this study.

The results confirm that even the samples with the highest concentrations of the active agents (chitosan 2.5% and PVA 2%; specifically, S32, P32, and K32) exhibit excellent biocompatibility. Although these samples possess the highest solid add-on to provide long-term antibacterial protection, the toxicity test confirms that this increased concentration does not compromise the safety of the materials.

Therefore, based on the experimental data, all coated samples prepared via the three different methods are safe and non-toxic. Among them, the highest-concentration formulations (S32, P32, and K32) remain the most promising samples for wound dressing applications, as they combine maximum antibacterial efficacy and solid add-on with proven in vivo safety and biocompatibility.

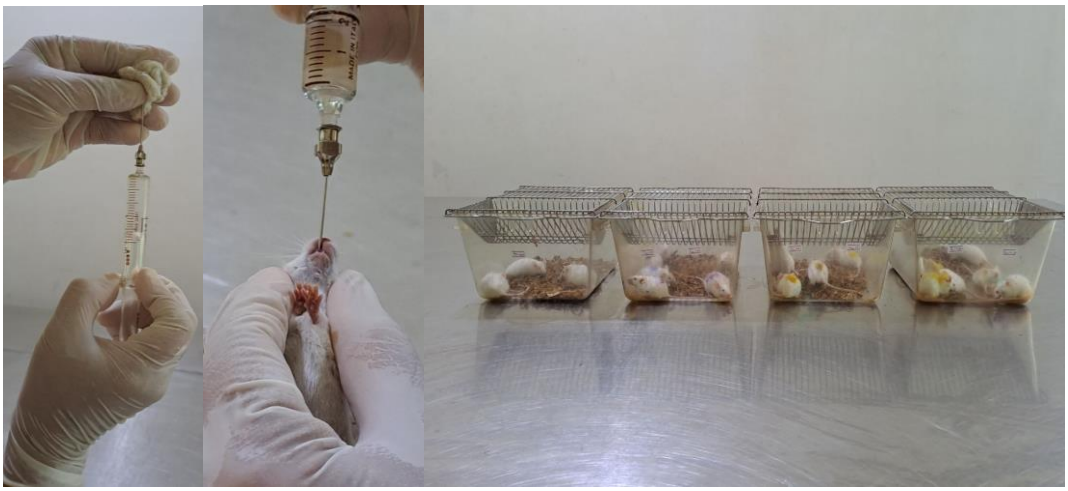


Figure.1. Representative Mice After Treatment with Extract Solution from Cs/PVA Coated Samples (Day 1)



Figure.2. Representative Mice After Treatment with Extract Solution from Cs/PVA Coated Samples (Day 14)

6. Conclusion

The results clearly demonstrate that the coating method significantly dictates the final properties of the fabric. The padding method yields the highest fabric weight (S32 = 10.62 g/m²) due to the high wet pick-up and deep penetration of the viscous solution into the fiber structure. The screen coating method produces the highest fabric thickness (P32 = 0.1140 mm) because the high solid content creates a thick, continuous polymeric film on the surface. The blade coating method results in intermediate weight and thickness but exhibits the most superior functional properties. This method provides relatively uniform distribution of the polymer on the fabric surface and allows the coating to penetrate into the spaces between the fibers. This may form a porous coating structure that can hold more water and support the fabric structure. Consequently, the blade-coated samples show the highest swelling value (K32 = 435.29%) and the highest tensile strength (K32 = 486.36 cN).

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