DEVELOPMENT OF COMPOSITE TEXTILE STRUCTURES FOR WOUND DRESSING APPLICATIONS

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ABSTRACT

The main objective of this research work was the development of novel and responsive nonwoven composite structures containing gelling materials for wound management. The study mainly focused on the development of novel all inclusive collagen-booster therapeutic nonwoven wound dressings that also provide essential functional properties such as high absorption, vertical and lateral wicking, antibacterial and acidic pH properties. The developed composite wound dressing consists of carboxymethylcellulose (CMC) fibre and also it was reinforced with polylactic acid (PLA) fibre. The produced composite wound dressings were treated with two different collagen boosters at 4% (g/L) by using the spray method. The details of the collagen boosters have not been disclosed in this paper due to the Intellectual Property Rights (IPR) issues. The important benefit of using collagen booster treatment is that it allows the maintenance of an acidic pH environment at the wound area. It is well known that acidic pH reduces the wound healing time and enhances the wound healing process. Furthermore, one of the collagen boosters promotes not only the proliferation of the epithelial cells in wounds but also can provide antibacterial action.

The PLA fibre reinforced CMC composite dressing has enhanced wicking properties which help to minimise the pooling of exudate on the wound bed and as a result maceration is prevented. The collagen boosters treated dressings maintain the wound bed in an acidic pH condition which also improves the wound healing process. In addition to the above stated properties, the collagen booster treatment imparts antimicrobial activity against Gram-positive and Gram-negative bacteria, thus resulting in the reduction in the propensity for wound infection. Ultimately, the research has proved that the 4% collagen booster treatment enhances the antimicrobial activity and the acidic pH characteristics of the developed CMC/PLA composite wound dressings.

Key Words: wound dressings, composite textiles, carboxymethylcellulose, polylactic acid, collagen boosting.

1. INTRODUCTION

The wound healing is influenced by both intrinsic and extrinsic factors. There is a considerable global variation in the treatment of acute and chronic wounds; therefore, establishing a standardised, best way to manage wounds may not be possible. Complete wound healing, which includes restoration of function, is hardly ever achieved in those disfigured by wounds especially when one includes the appearance of the skin or absence of an appendage[1-3]. The wound maceration (pooling) usually describes the results of excess and retention of moisture, which can delay the wound healing. The wound desiccation can also delay the wound healing. An optimal moist environment is crucial for wound healing process. Comprehensive wound assessment, which includes wound classification, colour, depth, shape, size, amount of exudate, wound location, and the environment of care will all influence the choice of the wound dressing [4]. The dressings can achieve the maximum absorption when

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they are applied on heavily exudating wounds. The optimum level of moisture has to be provided for reducing the wound healing time, conversely, the high levels of exudate combined with the pro-inflammatory mediators result in a detrimental effect on healing, including wound enlargement and damage to the periwound skin such as maceration and excoriation. It has been shown that when the wound exudate is absorbed and retained by the dressing, the maceration has been decreased [5]. However the dressing will make sure that pooling of exudate cannot take place at one point. In other words, enhanced lateral wicking will minimise the pooling of exudate at one point. The basic requirements of wound management are maintaining a moist environment at the wound surface and the removal of excess fluid from wound skin to prevent maceration or erosion of the wounds. The ability of a dressing to manage exudate and prevent maceration during healing is one of the most desirable properties for the cavity wound dressings [6]. It is established that maceration causes wound infection and the wound infection can delay the wound healing[7].

It has been demonstrated that pH has an essential role to play during the healing process and an acidic environment is more beneficial for the wound healing process [8-10]. The pH value within the wound environment directly and indirectly influences all of the biochemical reactions that take place during the healing process. The pH value is also a key determinant for the metabolism during wound healing and, therefore, is an important parameter for therapeutic interventions in wound care due to pH and biochemical reaction speed interaction [9]. Decreasing pH value of the wound surface is one of the essential requirements of the wound dressing material, although there has not been much research into this interaction. In previous studies, acetic acid in 1% and 5% solutions has been applied as a topical agent to reduce the pH of the wound surface[11,12]. Using acetic acid to reduce the pH is not an effective method, as the acetic acid can only decrease the pH for 1-hour period and, after that, the wound pH returns to the untreated pH value[13]. Another problem with using acetic acid is its availability; there is now no licensed sterile acetic acid agent for use in wound management [14].

The innovative aspects of this study principally consist of: 1) developing suitable structures by using appropriate fibres for wound management; 2) selection and optimisation of collagen boosting chemicals to enhance wound healing; 3) integration of collagen boosters into the optimised textile structures that contain different composites; and 4) testing and characterisation of collagen booster treated novel composites. The carboxymethylcellulose (CMC) and polylactic acid (PLA) fibres combination was chosen for this study. The developed novel composite dressing consists of two layers, the first layer is of CMC fibres which absorbs high amount of wound fluid and the second layer is of PLA fibres which diffuses the absorbed fluid around the wound dressing. The developed CMC/PLA composite wound dressing was treated with 4% collagen booster (CB) solution.

2. MATERIALS AND METHODS

The CMC staple fibres were kindly supplied by ConvaTec, UK. PLA fibres were kindly provided by Dorte Logemann, Bremen, Germany. The properties of the fibres above were tested and analysed (Table 1). Prior to producing nonwoven structures, the fibres were conditioned for 48 h in 65% relative humidity and 20°C temperature. The fibre linear density values were determined by using Vibromat M Tester (Textechno Company, Germany).

The single-fibre CMC, 75%/25%, CMC/PLA and 50%/50% CMC/PLA composite fabrics were produced by using the Automatex Laboratory Nonwoven Line, Nuova Automatex, Italy at the University of Bolton and their absorbency, wicking, pH and antibacterial activity were tested and analysed. Two different CB agents were blended with ratio of 3% (g/L) CB-1 and 1% (g/L) CB-2. This 4% CB solution was prepared by dissolving powders with a magnetic stirrer in 1% (g/L) acetic acid solution until the solution turns to transparent. The 4% CB solution temperature was 50^{o}C during the solution formation. The mixture was stirred for 30 min at this temperature. After complete dissolution, the solution had varying pH values from 4.0 to 5.0. The solution treatment of fabrics was done mainly by the spray coating technique at room temperature. The test solution A, which was prepared by dissolving 2.298 g sodium chloride and 0.368 g calcium chloride dihydrate in 1 L of distilled water, was used to simulate serum and wound fluid.

Table 1. Fibre properties

Property	CMC	PLA
Staple length/mm	50	50
Linear density/dtex	1.4	2.2

3. RESULTS AND DISCUSSION

The area density, thickness, and bulk density of the fabrics are given in Table 2. According to Table 2, the area densities of untreated fabrics were found to be much higher than the coated fabrics. The thickness of fabrics ranged from 3.6 mm to 4.4 mm. The most obvious finding to emerge from the physical characterisation of the fabrics is that the fabric properties were affected by the spray coating process.

Table 2. Area density, thickness and bulk density

Fabrics	**Area density ($g \cdot m^{-2}$)**	**Thickness (mm)**	**Bulk density ($g \cdot cm^{-3}$)**
100% CMC Untreated	220±15.9	3.8	0.059
100% CMC 4% CB solution treated	190±20.1	4.0	0.048
75%/25% CMC/PLA Untreated	190±8.8	4.4	0.043
75%/25% CMC/PLA 4% CB solution treated	189±5.1	3.9	0.048
50%/50% CMC/PLA Untreated	198±11.1	4.1	0.048
50%/50% CMC/PLA 4% CB solution treated	187±15.0	3.6	0.051

3.1 Absorbency and Wicking Properties

The absorbency, vertical and lateral wicking, and the rate of absorption results are shown in Table 3. It was observed that 50%/50% CMC/PLA fabric had the lowest absorbency value with 75%/25% CMC/PLA fabric showing a better absorbency value. This study confirmed that PLA containing fabric had somewhat decreased absorbency as compared with single-fibre CMC fabric. On the other hand, PLA fibres helped to increase the vertical and lateral wicking properties significantly, which was one of the most important objectives of this research work. It is also worth mentioning that the treatment did not affect other properties tested considerably. The wicking properties of the single-fibre CMC dressing have been enhanced by using PLA fibre reinforcement. This will help in stopping the pooling of the exudate in one specific area of the wound dressing. The enhanced wicking can reduce the risk of maceration.

Table 3. Absorbency, rate of absorption, and wicking properties of fabrics

Fabrics	Absorbency ($g \cdot g^{-1}$)	Vertical wicking (mm)	Sinking time (s)	Lateral wicking area (%)
100% CMC Untreated	20.4±0.6	7	3.2	122
100% CMC 4% CB solution treated	20.1±0.9	7	1.6	135
75%/25% CMC/PLA Untreated	16.6±1.2	25	1.3	386
75%/25% CMC/PLA 4% CB solution treated	16.4±0.9	26	1.6	369
50%/50% CMC/PLA Untreated	15.5±0.5	36	2.0	591
50%/50% CMC/PLA 4% CB solution treated	15.5±0.6	35	2.1	603

3.2 pH and Antimicrobial Properties of Treated Fabrics

The mean values from day 1 to day 7 for each fabric in solution A are given in Table 4. In all cases, the pH values of solution A decreased with the immersion of fabrics in it. The pH value of treated fabric immersed in solution A gradually decreased over time. The most important result to emerge from the data was that 4%solution treated fabrics had considerably lower pH value as compared to their untreated counterparts. It can be concluded from these results that the 4% solution treatment can provide the desired acidic pH of ≤ 4.0 which helps to enhance the wound healing process.

Table 4. Mean pH and zone of inhibition values of developed dressings

Fabrics	Mean pH (over 7 days)	Staphylococcus aureus 10^{-1} (mm)	Escherichia coli 10^{-3} (mm)
Solution A	5.72±0.15	N/A	N/A
100% CMC Untreated	5.17±0.11	0.0	0.0
100% CMC 4% CB solution treated	3.49±0.21	9.1	8.8
75%/25% CMC/PLA Untreated	5.15±0.20	0.0	0.0
75%/25% CMC/PLA 4% CB solution treated	3.92±0.16	10.3	9.2
50%/50% CMC/PLA Untreated	5.10±0.25	0.0	0.0
50%/50% CMC/PLA 4% CB solution treated	3.85±0.15	10.1	5.1

The *S. aureus* bacteria at 10^{-1} dilution and the *E. coli* bacteria at 10^{-3} dilution were studied to determine the antibacterial activity of 4% CB treated fabrics. The zone of inhibition values are tabulated in Table 4 and are depicted in Fig. 1. The untreated fabrics did not show any zone of inhibition. It is clear from Fig. 1 that all 4% CB treated fabrics demonstrate promising zone of inhibition. It can thus be concluded that the blend of CBs at acidic pH can be effectively employed for achieving the antibacterial activity of the developed wound dressings which is one of the main objectives of this study.

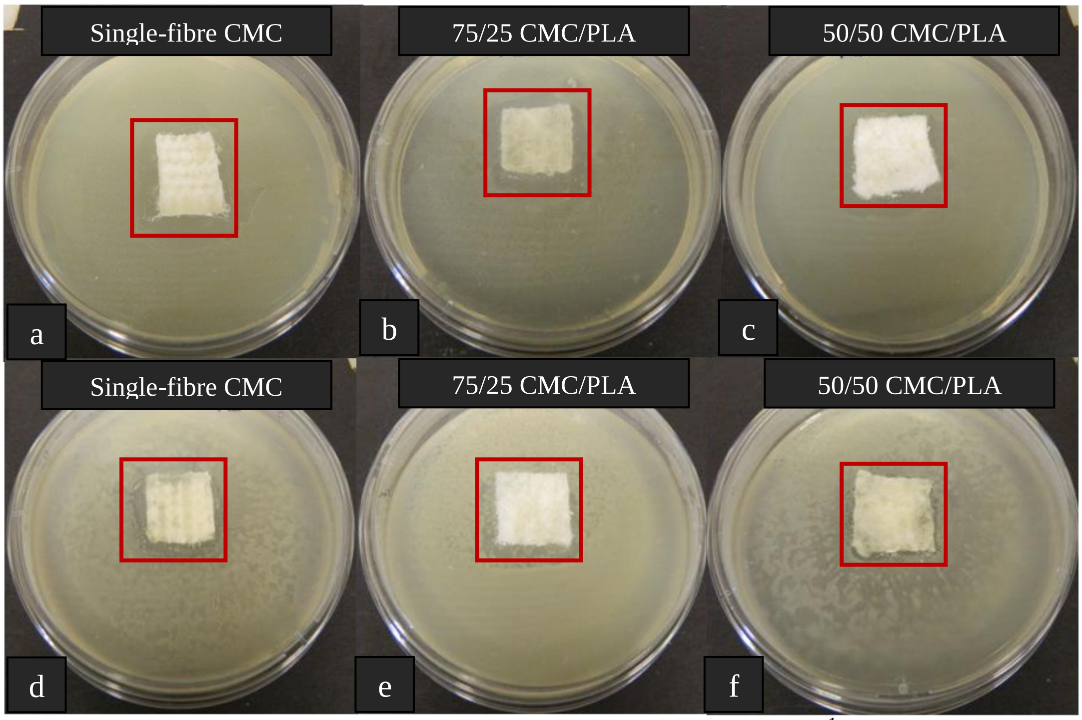

Figure 1. Zone of inhibition of 4% CB treated fabrics against s. aureus at 10^{-1} (a, b, c) and e. coli at 10^{-3} (d, e, f).

4. CONCLUSIONS

The overall functional properties of the single-fibre CMC dressing have been enhanced by using PLA reinforcement. The enhanced wicking can reduce the risk of maceration and infection. It needs to be stressed that the PLA reinforcement has not influenced the higher absorbency properties of the CMC dressings considerably. The CMC/PLA dressing still has a higher absorbency than alginate dressing[15], which is one of the well-known high absorbent wound dressings. The developed PLA containing novel dressing possesses the desired fluid absorption and wicking properties which make the PLA fibres an ideal reinforcement to be incorporated into the CMC fibres. The incorporation of PLA fibres in composite structures for wound dressing application can also be considered as an ecologically friendly combination mainly because of easy biodegradability. In addition, PLA fibres provide biocompatibility, non-toxic, high absorption and wicking properties.

After achieving the intended major structural properties, the developed novel CMC/PLA composite structures were treated with CBs. One of the major objectives of this research paper was to incorporate suitable CBs onto the novel composite dressings. Two different CBs have been successfully applied on the developed fabrics. The results suggest that 4 % CB (g/L) solution can produce the desirable attributes in the wound dressings. The 4% (g/L) CB solution treated fabrics exhibit the desired properties related to the acidic pH and antibacterial performance. The two major objectives of the study have been successfully achieved by CBs, one CB provides acidic pH and the other provides antibacterial property. The two CBs, contained in 4% solution, treated dressings delivered desired acidic pH and antibacterial in addition to enhancing the growth of collagen during wound healing. In general, these findings have important implications for developing “all-in-one” therapeutic nonwoven wound dressings. Finally, the best combination for achieving the desired properties have been observed from the 4% (g/L) CB solution treated 75%/25% CMC/PLA composite dressing. The findings of this study have a number of important implications for future practices in wound care; however, the *in vitro* observations need to be supported and confirmed by *in vivo* and clinical evaluations.

5. REFERENCES

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