Carbohydrate Polymers 90 (2012) 658–666

Contents lists available at SciVerse ScienceDirect

Carbohydrate Polymers

journal homepage: www.elsevier.com/locate/carbpol

Wound dressing based on nonwoven viscose fabrics

A. Abou-Okeil[a,*], A.M. Sheta[b], A. Amr[a], Marwa A. Ali[a]

[a] Textile Research Division, National Research Center, Dokki, Cairo, Egypt
[b] Faculty of Veterinary, Cairo University, Egypt

ARTICLE INFO

Article history:
Received 22 April 2012
Received in revised form 17 May 2012
Accepted 24 May 2012
Available online 1 June 2012

Keywords:
Wound dressing
Chitosan
PVA
Ag nanoparticles
Nonwoven viscose fabric
Wound healing

ABSTRACT

Nonwoven viscose fabric was treated with chitosan/polyvinyl alcohol (PVA) using pad-dry method, using different concentrations of chitosan and PVA. Increasing the amount of PVA leads to increasing of air permeability. Water permeability increased by increasing the amount of PVA to 2 ml (10% solution) then decreased by any increase of the quantity of PVA solution. Roughness increased with increasing the amount of 10% PVA solution. It is shown that roughness, water and air permeability increased with increasing the chitosan concentration. Antibacterial properties was increased with increasing PVA/or chitosan concentration. The chitosan/PVA treated nonwoven viscose fabric was immersed in a solution of Ag nanoparticles. The chitosan/PVA/Ag nanoparticles treated nonwoven fabrics were used as wound dressings on French white Bouscat rabbits, with age ranged from 1 to 2 years. A complete healing was achieved using wound dressing consists of nonwoven viscose fabric treated with chitosan/PVA/Ag nanoparticles after 21 days. The histopathological examination confirmed the complete re-epithelialization and averagely thick epidermis formation.

1. Introduction

Burns cause huge defects in the skin which are very serious (King, 2006). Previously, there were many types of wound dressings in the market (Nanchahal, Dover, & Otto, 2002; Ratner, Hoffman, Schoen, & Lemons, 1996; Soejima, Nozaki, Sasaki, Takeuchi, & Negishi, 1997; Yanaga et al., 2001). In the 1960s, wound dressings based on gauze and absorbent textile materials were not sufficient for wound management (Turner, 2001). Wound dressing should have certain requirements including short time healing, breathable to permit gases and water vapor exchange, antibacterial, non-toxic, etc. (Turner, 1979).

Wound dressings based on polysaccharides especially chitosan have been one of the most important wound dressings (Ong, Wu, Moochhala, Tan, & Lu, 2008; Shigemasa & Minami, 1995; Ueno, Mori, & Fujinaga, 2001). Chitosan is partially N-deacetylated chitin, and chitin is a linear homopolymer of 1,4 h-linked N-acetyl-D-glucosamine. Chitosan have many advantages to be used as wound dressing materials such as biodegradability, biocompatibility, anti-infectional activity, hemostatic activity, and ability to accelerate wound healing (Ishihara et al., 2002; Prudden, Mige, Hanson, Friedric, & Balassa, 1970; Shigemasa & Minami, 1995; Yang & Lin, 2004). There are many wound dressings based on chitosan and collagen (Wang, Su, & Chen, 2008) although the need for enhancing the water absorbability of wound dressings based on chitosan and collagen (Coulomb et al., 1998; Kwan et al., 2011; Michaeli & McPherson, 1990; Xu, Ma, Shi, Gao, & Han, 2007). To enhance the properties of chitosan to increase its hydrophilic characteristic it should be mixed with other polymer. PVA has some desired properties for application in wound dressing formulations such as nontoxic, have a little cell adhesion and protein absorption, PVA membranes were used for biomedical materials (Burczak, Gamian, & Kochman, 1996; Cascone, Sim, & Downes, 1995; Chandy & Sharma, 1992; Chuang, Young, Yao, & Chiu, 1999; Koyano, Koshizaki, Umehara, Nagura, & Minoura, 2000; Yang, Yao, Chang, & Chen, 1996; Yang, Chuang, Yao, & Chen, 1998, Paul & Sharma, 1997). According to the ability of PVA to interact with chitosan it was used in a mixture with chitosan for many biomedical applications (Chandy & Sharma, 1992; Chuang et al., 1999; Koyano et al., 2000; Minoura et al., 1998; Nakatsuka & Andrady, 1992; Sung et al., 2010).

Nonwoven fabrics have an important role in many industrial applications. The production of nonwoven fabrics can be classified according to web formation techniques (Sanjiv & Larry, 1993).

The important process of production of nonwoven fabrics is spun-bonding (Wooten, 1990). Spun-bonded nonwoven fabrics have a special specification such as high opacity per unit area, a layered structure which leads to increasing basis weight, high tear strength, good fray and crease resistance, high liquid retention and low drape-ability (Sanjiv & Larry, 1993). Spun-bonded webs could be used in medical applications due to its unique structure and cost-effective properties (Smorada, 1998).

* Corresponding author. Tel.: +20 2 33335939; fax: +20 2 33322424.
E-mail address: aokeil2004@yahoo.com (A. Abou-Okeil).

0144-8617/$ – see front matter
http://dx.doi.org/10.1016/j.carbpol.2012.05.093

The antibacterial effect of silver can be attributed to blocking of respiratory enzyme path ways and altering the DNA and cell wall. Some authors have recorded the wound healing effect of silver (Li, Diao, Zhang, & Liu, 2011; Tian et al., 2007). Dressings containing silver are widely used in the burn wounds treatment. Wound dressings containing silver act by absorbing the exudates and releasing silver onto the wound dressing, killing microorganisms in wound and within dressings or by killing bacteria inside the dressings without any release of silver ions (Templeton, 2005). In presence of fluids and exudates, silver is ionized to release the biologically active Ag^+ ions. Which link to negatively charged proteins, RNA, and DNA gram-negative and gram-positive bacteria, fungal cells and virus (Huang, Dai, Xuan, Tegos, & Hamblin, 2011; Mooney, Lippitt, & Friedman, 2006; Pinto et al., 2012).The aim of the present work is to study the effect of the treatment of nonwoven viscose fabric with chitosan/PVA/Ag nanoparticles on the mechanical and physical, antibacterial properties of the treated fabrics. The study will extend to investigate application of these treated fabrics as wound dressing material.

2. Methods

2.1. Materials

Chitosan, kindly supplied by Sigma, acetic acid, PVA, $AgNO_3$ and trisodium citrate are of laboratory grade chemicals. Three nonwoven fabrics were used in this study, 100% viscose (45 g/m^2); 30% viscose:70% polyester (30 g/m^2); and 30% polyester:70% viscose (45 g/m^2). The range of fiber length was 30–38 mm with fiber denier of nonwoven web 1.5–2 D. All nonwoven samples were produced by random distribution for web and spun bonded thermally.

Nine French white Bouscat rabbits; their age ranged from 1 to 2 years and their average weight about 5 kg that enjoyed the full requirements of health and safety according to the information records in the Department of Surgery, Anesthesiology and Radiology-Faculty of Veterinary Medicine, Cairo University.

2.2. Preparation of chitosan/PVA solution

Different chitosan concentrations in the range (0.2–0.8%) were prepared in 2% acetic acid solution and kept overnight to assure complete dissolution. PVA solutions were prepared by dissolving 10 g of PVA in 100 ml of distilled water; the temperature was raised to 80 °C with stirring until complete dissolution of PVA. Different volumes of 10% PVA solution on the range (2–14 ml) were added to the above chitosan solutions keeping the total volume 100 ml with continuous stirring to complete homogeneity. The solution of chitosan and PVA was kept overnight to get rid of the air bubbles.

2.3. Treatment of nonwoven fabrics with chitosan/PVA solution

Nonwoven fabrics were immersed in the chitosan/PVA solution, padded to wet pick up 120% and dried at 100 °C for 10 min. The fabrics were washed thoroughly with distilled water then dried at room temperature.

2.4. Preparation of Ag nanoparticles

Ag nanoparticles were synthesized by chemical reduction method (Šileikaitė, Prosyčevas, Puišo, Juraitis, & Guobienė, 2006). All solutions were prepared in distilled water. In a typical experiment, 50 ml of 1×10^{-3} M $AgNO_3$ was heated to boiling. To this solution 5 ml of 1% trisodium citrate was added drop wise. The solution was stirred vigorously at boiling until the color changed to pale yellow which is the evident of nanoparticles formation. The solution was cooled to room temperature; the mechanism of the reaction is as follows:

$$4Ag^+ + C_6H_5O_7Na_3 + 2H_2O \rightarrow 4Ag + C_6H_5O_7H_3 + 3Na^+ + H^+ + O_2$$

2.5. Treatment of chitosan/PVA treated nonwoven fabrics with Ag nanoparticles

The chitosan/PVA treated nonwoven samples (15 cm × 20 cm) were immersed in 30 ml of the prepared Ag-nanoparticles solution for 30 min squeezed between two filter papers to remove the excess solution then dried at 100 °C for 5 min.

2.6. The surgical operation

A pre-medication with xylazine (0.02 mg/kg) and diazepam (0.1 mg/kg) is given intramuscular injection (IM) followed by injection of ketamine (10–15 mg/kg) to induce anesthesia and production of muscle relaxation, sedation and analgesia. Nine aseptic circular skin incisions of 2 cm diameter were employed on the back area (Lipowitz, 1985), after shaving and cleansing with bitadine (10%). The rabbits were dressed with 9 samples of dressing: (1) nonwoven viscose without any treatment, (2) nonwoven fabrics treated with chitosan/PVA and (3) nonwoven fabrics treated with chitosan/PVA/Ag-nanoparticles.

2.7. Analysis

Physical and mechanical tests were carried out on the Textile Division at the National Research Center in Cairo. All samples are conducted by tests after conditioning the fabric for 24 h under the standard atmospheric conditions (20 ± 2 °C temperature, 65 ± 2% relative humidity). All Physical and mechanical tests were accepted for the fabrics before and after treatment.

2.7.1. Tensile strength and elongation

Tensile strength and elongation for both warp and weft direction was measured according to ASTM No. D-5035 (2006).

2.7.2. Air permeability

Air permeability was measured according to ASTM No. D-737 (1996).

2.7.3. Water permeability

Water permeability was measured according to ASTM No. D-461 (1993).

2.7.4. Instrumental analysis

Transmission electron microscope (TEM) was measured using Zeiss-EM10-Germany. FTIR spectroscopy was measured using FT-IR-FT-Raman, model: Nexus 670 (Nicolet-Madison-WI-USA). Cotton fabric was cut into very small pieces; these pieces were mixed with KBr. The spectral range was 400–4000 cm^{-1}. Scanning electron microscope (SEM), the samples were examined by a JEOL-840X scanning electron microscope, from Japan, magnification range 35–10,000, resolution 200 Å, acceleration voltage 19 kV. All the samples were coated with gold before SEM testing. Energy dispersive X-ray (EDX), the elemental ratio of prepared cotton fabric was characterized by SEM–EDS (electron dispersive spectroscopy) (JXA-840 an Electron Probe Microanalyzer-JOEL).

2.7.5. Antibacterial assessment

For antibacterial experiment, *Staphylococcus aureus* (*S. aureus*, Gram-positive bacteria) and *Escherichia coli* (*E. coli*, Gram-negative bacteria) were used. The antibacterial activity of the fabrics was

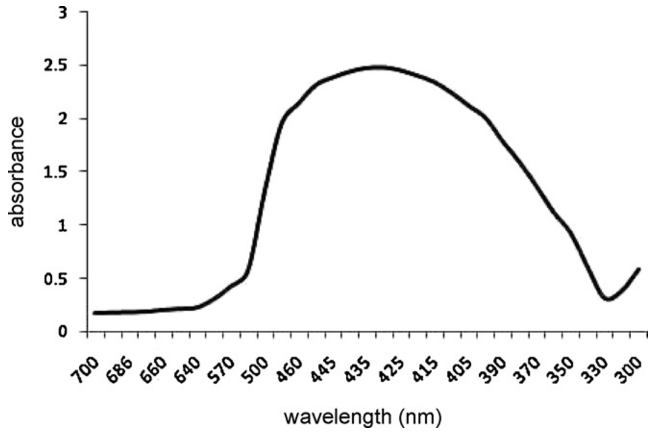

Fig. 1. UV–vis-spectroscopy of Ag nanoparticles.

measured by the inhibition zone method (Qin, Zhu, Chen, & zhang, 2006).

2.7.6. Clinical observations and histopathological studies

After leaving the experimental animal free for a period of 21 days for subsistence during which data recording state of health experimental animals as a temperature, respiratory rate, heart rate, color mucous membranes, skin and superficial gloss eye as well on its way of food and drink (Williams & Wilkins, 1997). Autopsy samples were taken from the healed skin after euthanasia, 21 days after implantation. Samples were examined macroscopically then fixed and stained with hematoxylin and eosin stains for microscopic examination (Bancroft, Stevens, & Turner, 1996).

3. Results and discussion

3.1. Preparation of Ag nanoparticles

Fig. 1 shows UV spectrum of Ag nanoparticles solution. It is clear from Fig. 1 that the characteristic surface plasmon (SP) resonance band of Ag nanoparticles centered at about 430 nm. TEM of Ag nanoparticles is shown at Fig. 2a. It is evident from Fig. 2a that Ag nanoparticles are almost spherical with particle size range of 6–10 nm, which provide a strong evidence of the UV–vis results.

3.2. Treatment of viscose nonwoven fabric with chitosan and PVA

3.2.1. Effect of PVA concentration on the mechanical and physical properties of nonwoven fabrics

Table 1 shows the effect of PVA concentration on the mechanical and physical properties of nonwoven fabric made of viscose. This Fabric was treated with a solution containing 0.6 g chitosan in 100 ml of 2% acetic acid and different volumes of 10% PVA solution (2, 6, 14 ml). The fabrics were immersed in these solutions, padded to wet pick up 120%, dried at 80 °C for 10 min, washed thoroughly with distilled water and finally air dried. Table 1 shows the effect of PVA concentration on the tensile strength, elongation, air permeability, water permeability and roughness of the fabrics. It can be noticed from Table 1 that TS decreases by using 2 ml of 10% PVA solution then increases by using 6 and 14 ml of 10% PVA solutions. This can be attributed to the structural distortion occurred according to the wet treatment, this distortion was enhanced by the presence of acetic acid which has an adverse effect on viscose fibers especially at high temperature for a long time. Increasing the TS at higher concentration of PVA can be explained by the protection and stabilization effect of PVA to the fiber structure. Table 1 shows also that EL decreases with increasing the amount of PVA which is in accordance with the ability of PVA to form a homogeneous rigid film on the surface of the fabrics.

Increasing the amount of PVA leads to increasing of air permeability which can be attributed to the increase in the extent of the structure opening. In case of water permeability it increases by increasing the PVA concentration to 2 ml then decreased by any increase of PVA concentration. This increase in water permeability can be explained by increasing the hydrophilic properties of the fabrics according to the presence of PVA on its surface while the decrease in water permeability with increasing PVA concentration to values higher than 2 ml can be explained by the ability of PVA to form a thin film on the surface of the fabric leading to decreasing the number and the size of pores. Table 1 shows also that roughness of the treated fabrics increases with increasing the amount of 10% PVA solution.

3.2.2. Effect of chitosan concentration on the mechanical and physical properties of nonwoven fabrics

Table 2 shows the effect of chitosan concentration on the tensile strength, elongation, air permeability, water permeability and roughness, of the treated fabrics. The nonwoven fabrics were treated with a solution containing 0.2–0.8 g chitosan in 100 ml of 2% acetic acid and 14 ml of 10% PVA solution. The fabrics were immersed in these solutions, padded to pick up 120%, dried at 80 °C for 10 min, washed thoroughly with distilled water and finally air dried.

Table 2 shows that increasing chitosan concentration has almost no effect on the TS and EL up to 6%, while increasing chitosan concentration to 8% leads to decreasing in EL. Table 2 shows also that roughness increases with increasing the chitosan concentration. Increasing the water and air permeability of the treated fabrics can be monitored by the increasing the pore size and also the distortion of the web structure.

3.2.3. Effect of fabric composition on the mechanical and physical properties of nonwoven fabrics

In his study three fabric compositions were used: 100% viscose; 70% viscose/30% polyester and 30% viscose/70% polyester. These fabrics were treated with a solution containing, 0.8 g chitosan in 100 ml of 2% acetic acid and 14 ml of 10% PVA solution. The fabrics were immersed in this solution, padded to pick up 120%, dried at 80 °C for 10 min, washed thoroughly with distilled water and finally air dried.

It is clear that changing the fabric composition has an important effect on TS, EL, water and air permeability and roughness. Table 3 shows that increasing the amount of polyester leads to decrease in the TS (Gupta, 1998). EL increases by increasing polyester content. It is clear also from Table 3 that air permeability increases with increasing the amount of polyester. This phenomenon can be explained by producing a higher amount of pores with different areas in the structure as a result of blending of two fibers one synthetic and the other natural, in addition to the range of fibers denier in the fabric and the random distribution of the fibers in the web. Water permeability decreases with increasing polyester in the structure that is due to increasing the hydrophobicity of the fabric according to increasing the amount of polyester. The roughness increases with increasing the amount of polyester which can be explained by the rough nature of polyester fabric.

3.2.4. Effect of Ag nanoparticles on the mechanical and physical properties of nonwoven fabrics

It is clear that treating the chitosan/PVA treated fabric with Ag nanoparticles has almost a marginal effect on the physical and mechanical properties of treated fabrics. The important effect is turning the color of the fabric to the pale brown.

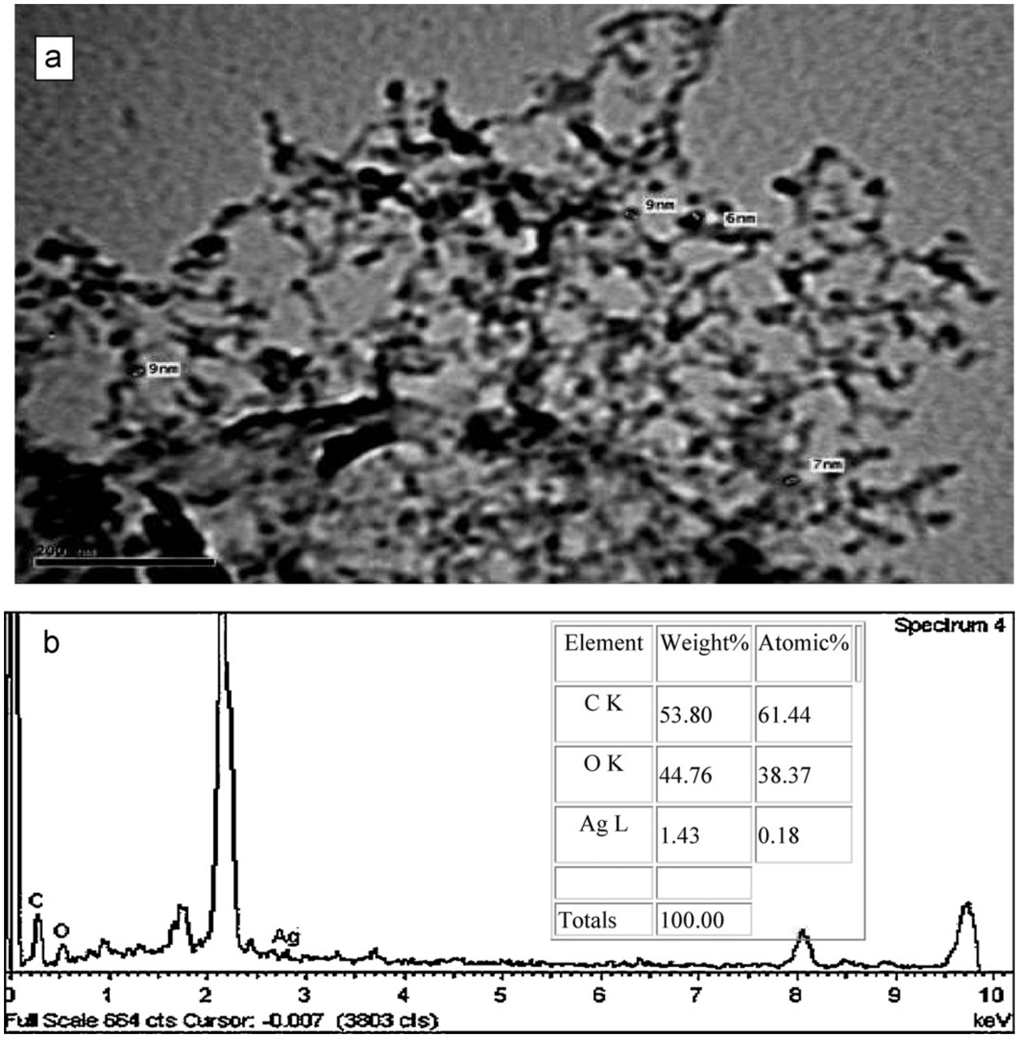

Fig. 2. TEM of Ag nanoparticles and EDX of the viscose fabrics treated with chitosan/PVA/Ag.

Table 1
Effect of PVA concentration on the mechanical and physical properties of nonwoven viscose fabric.

Test	Before treatment		2 ml of 10% PVA		6 ml of 10% PVA		14 ml of 10% PVA	
	D. Mach.	ID. Mach.	D. Mach.	ID. Mach.	D. Mach.	ID. Mach.	D. Mach.	ID. Mach.
Tensile strength	10.1 kg/cm	4 kg/cm	7.4 kg/cm	1.1 kg/cm	8.3 kg/cm	1 kg/cm	8.4 kg/cm	1.3 kg/cm
Elongation	66%	71%	24%	55%	12%	50%	11%	20%
Air permeability	146.6 $cm^3/cm^2/s$		209.26 $cm^3/cm^2/s$		237.55 $cm^3/cm^2/s$		250.00 $cm^3/cm^2/s$	
Water permeability	0.11 $cm^3/cm^2/s$		0.83 $cm^3/cm^2/s$		0.67 $cm^3/cm^2/s$		0.50 $cm^3/cm^2/s$	
Roughness	15.80 μm		16.94 μm		17.22 μm		17.53 μm	

Fabrics treated with 0.6% chitosan, different volume of 10% PVA, padded to 120% wet pick up, dried at 100 °C for 10 min; D. Mach. = in direction of the machine, ID. Mach. = cross the direction of the machine.

Table 2
Effect of chitosan concentration on the mechanical and physical properties of nonwoven viscose fabric.

Test	0.2% Chitosan		0.4% Chitosan		0.6% Chitosan		0.8% Chitosan	
	D. Mach.	ID. Mach.	D. Mach.	ID. Mach.	D. Mach.	ID. Mach.	D. Mach.	ID. Mach.
Tensile strength	8.4 kg/cm	1.3 kg/cm	8.4 kg/cm	1.3 kg/cm	8.4 kg/cm	1.3 kg/cm	8.7 kg/cm	1.3 kg/cm
Elongation	21%	20%	20%	21%	21%	20%	17%	18%
Air permeability	250 $cm^3/cm^2/s$		253.43 $cm^3/cm^2/s$		255.00 $cm^3/cm^2/s$		264.14 $cm^3/cm^2/s$	
Water permeability	0.50 $cm^3/cm^2/s$		0.51 $cm^3/cm^2/s$		0.54 $cm^3/cm^2/s$		0.66 $cm^3/cm^2/s$	
Roughness coefficient	17.23 μm		18.02 μm		18.05 μm		18.83 μm	

Fabrics treated with different concentration of chitosan, 14 ml of 10% PVA, padded to 120% wet pick up, dried at 100 °C for 10 min; D. Mach. = in direction of the machine, ID. Mach. = cross the direction of the machine.

Table 3
Effect of fabric composition on the mechanical and physical properties of treated fabrics.

Test	100% Viscose		70% Viscose, 30% polyester		30% Viscose, 70% polyester	
	D. Mach.	ID. Mach.	D. Mach.	ID. Mach.	D. Mach.	ID. Mach.
Tensile strength	8.7 kg/cm	1.3 kg/cm	6.8 kg/cm	2.8 kg/cm	4.4 kg/cm	1.6 kg/cm
Elongation	17%	18%	49.8%	70%	53.9%	80%
Air permeability	264.14 $cm^3/cm^2/s$		313.6 $cm^3/cm^2/s$		Over 402 $cm^3/cm^2/s$	
Water permeability	0.63 $cm^3/cm^2/s$		0.45 $cm^3/cm^2/s$		0.44 cm3/cm2/s	
Roughness	18.83 μm		20.27 μm		19.26 μm	

Fabrics treated with 0.8% chitosan, 14 ml of 10% PVA, padded to 120% wet pick up, dried at 100 °C for 10 min; D. Mach. = in direction of the machine, ID. Mach. = cross direction of the machine.

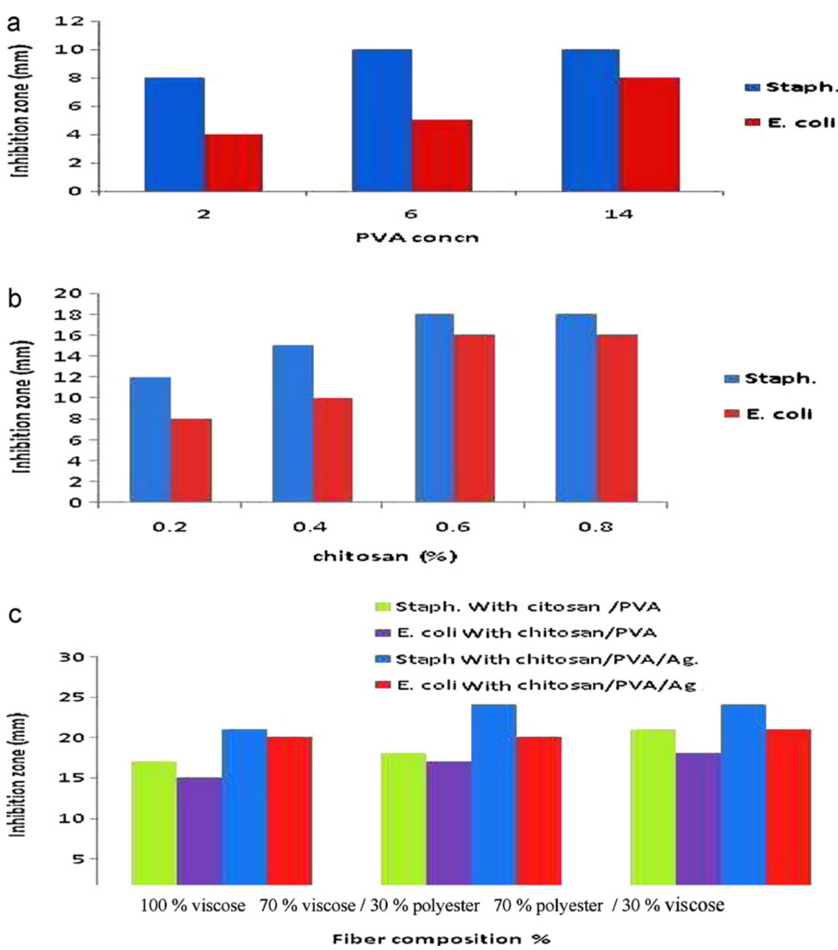

Fig. 3. Effect of treatment on the antibacterial properties of the treated fabric. (a) Effect of PVA on the antibacterial properties of treated viscose fabric. Fabrics treated with 0.6% chitosan, different volume of 10% PVA, padded to 120% wet pick up, dried at 100 °C for 10 min. (b) Effect of chitosan on the antibacterial properties of viscose fabric. Fabrics treated with different concentration of chitosan, 14 ml of 10% PVA, padded to 120% wet pick up, dried at 100 °C for 10 min. (c) Effect of Ag nanoparticles and fiber composition on the antibacterial properties of treated fabrics. Fabrics treated with 0.8% chitosan, 14 ml of 10% PVA, padded to 120% wet pick up, and dried at 100 °C for 10 min.

3.2.5. Antibacterial properties of treated nonwoven viscose fabrics

Fig. 3a–c shows the effect of PVA, chitosan, Ag nanoparticles and the type of the fabric on the antibacterial properties expressed as inhibition zone (mm) in Fig. 3a and b the treatment was done on 100% viscose fabric. Fig. 3a indicates that increasing PVA concentration leads to increasing in the antibacterial properties against *S. aureus* and *E. coli*. It is clear from Fig. 3a that the inhibition zone of the *S. aureus* is higher than that of *E. coli* which is Gram negative bacteria, this can be attributed to the high resistant of the Gram-negative bacteria according to the differences in the structure between the Gram-negative bacteria and Gram-positive bacteria. Fig. 3b shows the effect of chitosan concentration on the antibacterial properties of the treated fabrics. Fig. 3b indicates that increasing the antibacterial properties with increasing the concentration of chitosan. Also it is shown that inhibition zone of the Staph is higher than in case of *E. coli*. Fig. 3c explains the effect of presence of Ag nanoparticles along with the effect of the type of the fabric on the antibacterial properties of the treated fabrics. It can be concluded that in all types of fabrics the presence of Ag nanoparticles leads to increasing in the inhibition zone with respect to both type of bacteria. These results can be attributed to the ability of Ag nanoparticles to block respiratory enzyme path ways and altering the DNA and cell wall. The type of the fabric has also an important effect that is increasing the quantity of polyester on the fabric composition leads to increasing in antibacterial properties in presence and absence of Ag nanoparticles.

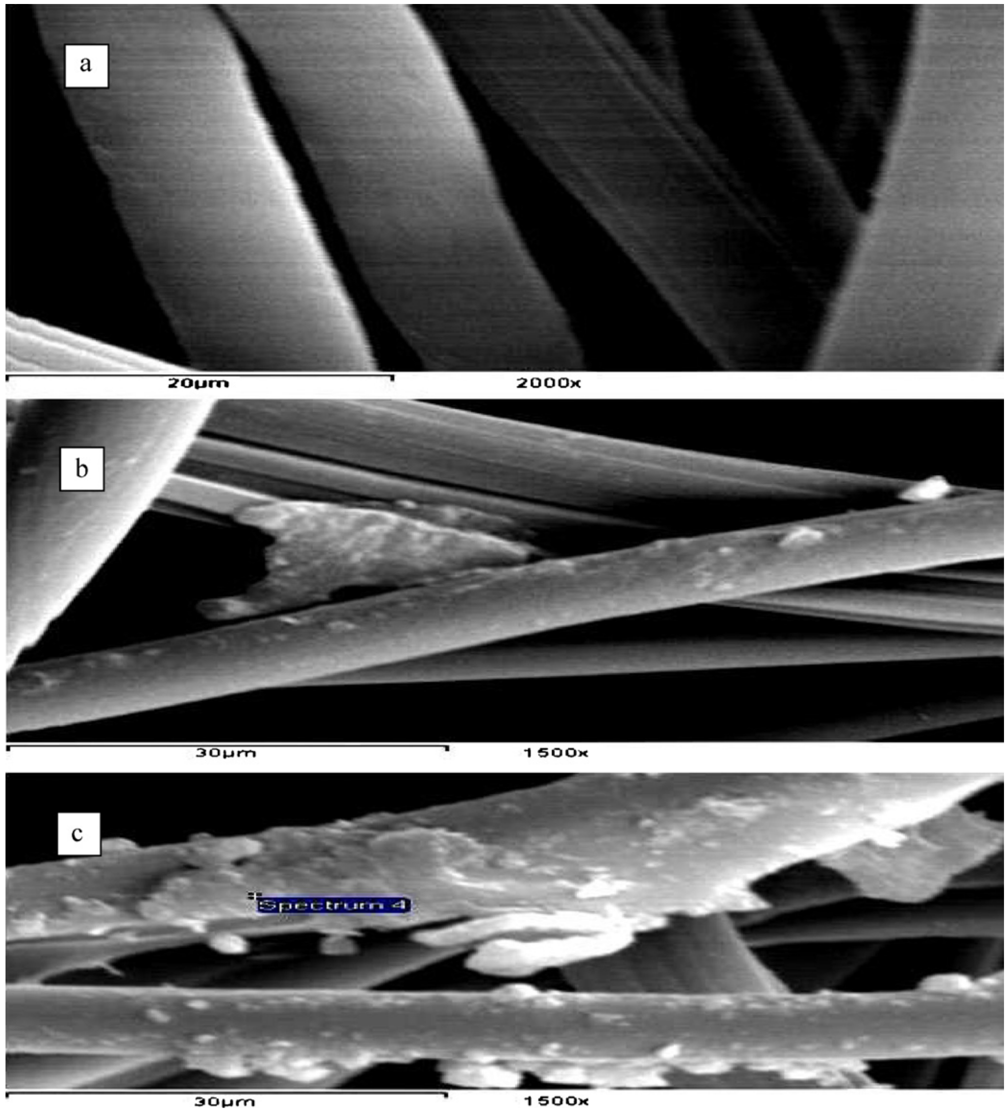

Fig. 4. SEM images of untreated and treated viscose fabrics. (a) Viscose fabric, (b) viscose fabric treated with chitosan/PVA and (c) viscose fabric treated with chitosan/PVA/Ag nanoparticles.

3.2.6. SEM

Fig. 4 shows the SEM images of untreated nonwoven viscose fabric, nonwoven viscose fabric treated with 0.8% chitosan in presence of 14 ml of 10% PVA solution, and nonwoven viscose fabric treated with 0.8% chitosan in presence of 14 ml of 10% PVA solution followed by treatment with Ag nanoparticles. The morphology of untreated viscose was significant different from the viscose treated with chitosan and PVA. It is very obvious from Fig. 4b the deposition of chitosan and/or PVA on the surface of viscose fabric. Also it is clear that the porous structure of untreated fabric was very different from the viscose treated with chitosan and PVA. It can be indicated from Fig. 4a and b increasing the pore size in the viscose fabric treated with chitosan and PVA. The extent of surface coating increased in presence of Ag nanoparticles (Fig. 4c).

3.2.7. EDX of the chitosan/PVA/Ag nanoparticles treated nonwoven viscose

Fig. 2b presents the EDX of nonwoven viscose fabric treated with 0.8% chitosan in presence of 14 ml of 10% PVA solution followed by treatment with Ag nanoparticles. Fig. 2b gives the evidence of the presence of Ag nanoparticles on the surface of nonwoven viscose fabric. Also the table of atomic and weight percentage assures the presence of Ag nanoparticles with 1.43 wt% on the treated nonwoven viscose fabric.

3.2.8. Clinical examinations

It was observed that the operated rabbits along 21 days survival post-surgery were apparently healthy with good eye luster and normal appetite. Moreover, the body temperature, respiratory rate, heart beats and mucous membranes coloration were also normal.

3.2.9. Wound closure examination

Fig. 5 shows the photographs of wounds dressed as follows: from the back of animal the wounds were dressed with 3 nonwoven fabrics without any treatment (100% viscose, 70% viscose/30% polyester; 30% viscose/70% polestar); in the middle of the animal body the wound dressed with the same three fabrics samples but treated with chitosan/PVA; in the front of animal body there are three dressings with the same fabrics but treated with chitosan/PVA/Ag nanoparticles. It can be indicated that after 21 days (Fig. 5) post-operation shows the wound treated with nonwoven 100% viscose fabric treated with chitosan/PVA/Ag nanoparticles was almost healed completely. The healed wounds have normal skin appearance and the hair begins to growth if compared

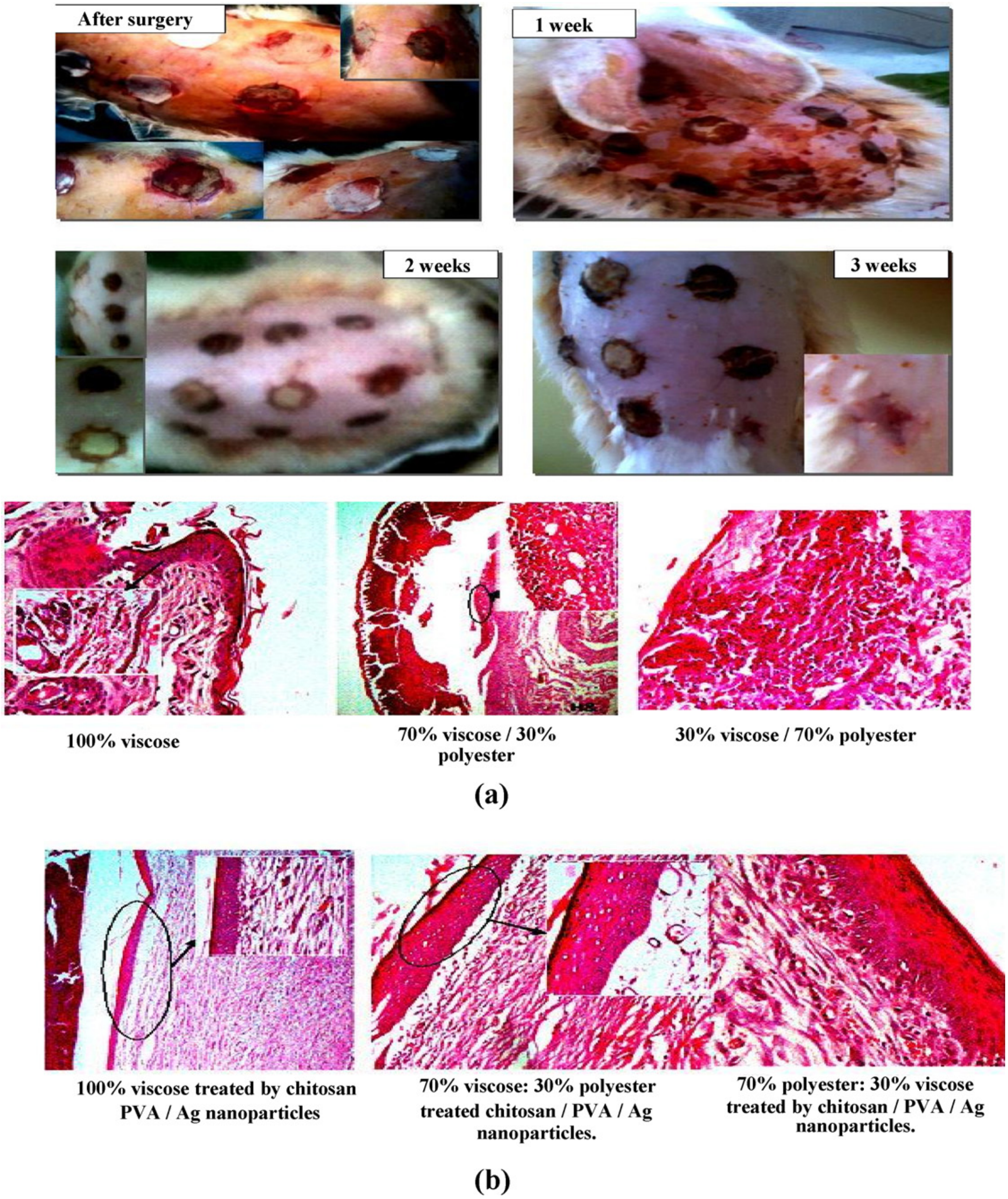

Fig. 5. Wound healing photographs and representative histopathological profiles of skin after 21 days. (a) Group 1 (fabrics without any treatment) and (b) group 2 (fabrics treated with chitosan/PVA/Ag nanoparticles).

with the other wounds which did not heal completely. It was found that the wound dressing composed of 100% nonwoven viscose/chitosan/PVA/Ag nanoparticles adhered uniformly to the surface of wound than the other formulations. This dressing was more swellable, flexible, elastic, air and water permeable than the other dressings, in addition to the high antibacterial properties. This dressing acts by absorbing the exudates and releasing the Ag onto the dressing, killing the microorganism on the wound and on the dressing or killing the bacteria within the dressing without any release of Ag ions (Li et al., 2011; Templeton, 2005). Ag ions bind to the negatively charged proteins, RNA and DNA in most gram-negative and gram-positive bacteria, fungal cells and virus (Huang et al., 2011; Mooney et al., 2006; Pinto et al., 2012). Chitosan and PVA have strong hydrophilic properties and have a good affinity to tissue which accelerates the process of healing. Moist-state materials covering a wound and absorb the exudates can maintain the wound in natural moist condition and reduce the risk of dehydration (Mathews & Harding, 1994). Ag nanoparticles may decrease the inflammation through modulation of cytokines (Tian et al., 2007).

3.2.10. Histopathological examination

The histopathological results pointed to that the higher the proportion of natural materials in the fabrics helped to the tissue proliferation and new vitality cells consequently, viscose fabric recorded the best results. In addition to the special properties of spun-bonded nonwoven fabric which are responsible for medical use such as, breathability, resistance to fluid penetration, lint-free structure, sterilizability, and impermeability to bacteria (Kondo & Ohshima, 1996). The histological studies were evaluated for 2 groups of wounds dressed as follows: group 1 dressed with 3 samples consists of 100% nonwoven viscose fabric; 70% viscose/30% polyester; 30% viscose/70% polyester without any treatment. Group

2 dressed with the same three fabric composition but treated with 0.8% chitosan/14 ml of 10% PVA/Ag nanoparticles. Fig. 5a shows the results of group 1. It is clear that using 100% viscose fabric leads to fibrosis, revascularization within sub-epithelial granulation tissue and forming a thin re-epithelialized epidermis, while using the other two types of fabric composition leads to ulcerated epithelium, overlying crust and underlying granulation tissue. The results of group 1 indicate that viscose fabric is the preferred fabric which can be explained by its natural origin, hydrophilic properties and its ability to permit the exchange of air and water vapor. Group 2 shows the effect of treatment of the three types of fabric composition (100% viscose, 70% viscose/30% polyester and 30% viscose/70% polyester) with 0.8% chitosan/14 ml of 10% PVA/Ag nanoparticles. Fig. 5b indicates that viscose fabric treated with 0.8% chitosan/14 ml of 10% PVA/Ag nanoparticles shows a complete re-epithelialization, averagely thick epidermis, underlying neovascularization, fibrosis and inflammatory cells. Using 70% viscose/30% polyester treated with 0.8% chitosan/14 ml of 10% PVA/Ag nanoparticles leads to wide fibrotic granulation tissue beneath completely re-epithelialized averagely thick epidermis, the small snapshot zooming shows prominent basal cell layer, under lying edema, thin newly formed vessels and inflammatory cells. Using 30% viscose/70% polyester treated with 0.8% chitosan/14 ml of 10% PVA/Ag nanoparticles shows completely re-epithelialized, averagely thick epidermis with basal cell hyperplasia and underlying granulation tissue.

4. Conclusion

Different nonwoven fabrics (viscose and viscose blended with polyester) were treated with chitosan/PVA/Ag nanoparticles. These fabrics were used as wound dressings on French white Bouscat rabbits, with age ranged from 1 to 2 years. From the results obtained it can be concluded that, viscose fabric treated with chitosan/PVA/Ag nanoparticles is the best one between these fabrics according to natural origin and its ability to permit the exchange of air and water vapor, in addition to its ability to swell. The wound dressed with this fabric is healed completely after 21 days with complete re-epithelialization, averagely thick epidermis, underlying neovascularization, fibrosis and inflammatory cells.

References

Bancroft, D., Stevens, A., & Turner, R. (1996). *Theory and practice of histological techniques* (4th ed.). Edinburg, London, Melbourne: Churchill Livingstone.

Burczak, K., Gamian, E., & Kochman, A. (1996). Long-term in vivo performance and biocompatibility of poly(vinyl alcohol) hydrogel macrocapsules for hybrid-type artificial pancreas. *Biomaterials*, *17*, 2351–2356.

Cascone, M. G., Sim, B., & Downes, S. (1995). Blends of synthetic and natural polymers as drug delivery systems for growth hormone. *Biomaterials*, *16*, 569–574.

Chandy, T., & Sharma, C. P. (1992). Prostaglandin E1-immobilized poly(vinyl alcohol)-blended chitosan membranes: Blood compatibility and permeability properties. *Journal of Applied Polymer Science*, *44*, 2145–2156.

Chuang, W. Y., Young, T. H., Yao, C. H., & Chiu, W. Y. (1999). Properties of the poly(vinyl alcohol)/chitosan blend and its effect on the culture off fibroblast in vitro. *Biomaterials*, *20*, 1479–1487.

Coulomb, B., Friteau, L., Baruch, J., Guilbaud, J., Chetien-Marquet, B., Glicenstein, J., et al. (1998). Advantage of the presence of living dermal fibroblasts within in vitro reconstructed skin for grafting in humans. *Plastic and Reconstructive Surgery*, *101*, 1891–1903.

Gupta, B. S. (1998). *Medical textile structures*. Medical Plastics and Biomaterials Magazine. MPB Article Index, p. 2.

Huang, L., Dai, T., Xuan, Y., Tegos, G. P., & Hamblin, M. R. (2011). Synergistic combination of chitosan acetate with nanoparticle silver as a topical antimicrobial: Efficacy against bacterial burn infections. *Antimicrobial Agents and Chemotherapy*, *55*(7), 3432–3438.

Ishihara, M., Nakanishi, K., Ono, K., Sato, M., Kikuchi, M., Saito, Y., et al. (2002). *Biomaterials*, *23*, 833–840.

King, P. (2006). Artificial skin reduces nutritional requirements in a severely burned child. *Burns*, *26*(5), 501–503.

Kondo, T., & Ohshima, T. (1996). The dynamic of inflammatory cytokines in the healing process of mouse skin wounds: A preliminary study for possible wound age determination. *International Journal of Legal Medicine*, *108*(5), 231–236.

Koyano, T., Koshizaki, N., Umehara, H., Nagura, M., & Minoura, N. (2000). Surface states of PVA/chitosan blended hydrogels. *Polymer*, *4*, 4461–4465.

Kwan, K. H. L., Liu, X., To, M. K. T., Yeung, K. W. K., Ho, C., & Wong, K. K. Y. (2011). Modulation of collagen alignment by silver nanoparticles results in better mechanical properties in wound healing. *Nanomedicine*, *7*, 497–504.

Li, D., Diao, J., Zhang, J., & Liu, J. (2011). Fabrication of new chitosan-based composite sponge containing silver nanoparticles and its antibacterial properties for wound dressing. *Journal of Nanoscience and Nanotechnology*, *11*(6), 4733–4738.

Lipowitz, A. T. (1985). In D. H. Slatter (Ed.), *Surgical biology: Textbook of small animal surgery*. London, Toronto Sydney, Tokyo: W.B. Sawnders Company.

Mathews, A., & Harding Ham, M. (1994). *Medical and hygiene textile production*. Nottingham, UK: Intermediate Technology Russell Press Ltd.

Michaeli, D., & McPherson, M. (1990). Immunologic study of artificial skin used in the treatment of thermal injuries. *Journal of Burn Care and Rehabilitation*, *11*(1), 21–26.

Minoura, N., Koyano, T., Koshizaki, N., Umehara, H., Nagura, M., & Kobayashi, K. (1998). Preparation, properties, and cell attachment/growth behavior of PVA/chitosan-blended hydrogels. *Materials Science and Engineering*, *6*, 275–280.

Mooney, E. K., Lippitt, C., & Friedman, J. (2006). Committee PSEFD. Silver dressings. *Plastic and Reconstructive Surgery*, *117*, 666–669.

Nakatsuka, S., & Andrady, A. L. (1992). Permeability of vitamin B-12 in chitosan membranes. Effect of crosslinking and blending with poly(vinyl alcohol) on permeability. *Journal of Applied Polymer Science*, *44*, 17–28.

Nanchahal, J., Dover, R., & Otto, W. R. (2002). Allogeneic skin substitutes applied to burns patients. *Burns*, *28*(3), 254–257.

Ong, S. Y., Wu, J., Moochhala, S. M., Tan, M. H., & Lu, J. (2008). Development of a chitosan-based wound dressing with improved hemostatic and antimicrobial properties. *Biomaterials*, *29*(32), 4323–4332.

Paul, W., & Sharma, C. P. (1997). Acetylsalicylic acid loaded poly (vinyl alcohol) hemodialysis membranes: Effect of drug release on blood compatibility and permeability. *Journal of Biomaterials Science. Polymer Edition*, *8*, 755–764.

Pinto, R. J., Fernandes, S. C., Freire, C. S., Sadocco, P., Causio, J., Neto, C. P., et al. (2012). Antibacterial activity of optically transparent nanocomposite films based on chitosan or its derivatives and silver nanoparticles. *Carbohydrate Research*, *348*, 77–83.

Prudden, J. F., Mige, L. P., Hanson, P., Friedric, H., & Balassa, L. (1970). The discovery of a potent pure chemical wound-healing accelerator. *American Journal of Surgery*, *119*(5), 560–564.

Qin, Y., Zhu, C., Chen, Y., & zhang, C. (2006). The absorption and release of silver and zinc ions by chitosan fibers. *Journal of Applied Polymer Science*, *101*, 766–771.

Ratner, B. D., Hoffman, A. S., Schoen, F. J., & Lemons, J. E. (1996). *Biomaterials science: An introduction to materials in medicine*. Elsevier Academic Press. p. 362.

Sanjiv, R. M., & Larry, C. W. (1993). *Nonwovens—Theory, process, performance & testing hand book* Atlanta, GA: TAPPI., pp. 180–181.

Shigemasa, Y., & Minami, S. (1995). Applications of chitin and chitosan as biomaterials. *Biotechnology & Genetic Engineering Reviews*, *13*, 383–420.

Šileikaitė, A., Prosyčevas, I., Puišo, J., Juraitis, A., & Guobienė, A. (2006). Analysis of silver nanoparticles produced by chemical reduction of silver salt solution. *Materials Science*, *12*(4), 287–291.

Smorada, R. L. (1998). *Encyclopedia of polymer science and engineering*. New York: John Wiley and Sons., p. 227.

Soejima, K., Nozaki, M., Sasaki, K., Takeuchi, M., & Negishi, N. (1997). Reconstruction of burn deformity using artificial dermis combined with thin split-skin grafting. *Burns*, *23*(6), 501–504.

Sung, H. S., Hwang, M., Kim, J. O., Lee, J. H., Kim, Y., Kim, J. H., et al. (2010). Gel characterization and in vivo evaluation of minocycline-loaded wound dressing with enhanced wound healing using polyvinyl alcohol and chitosan. *International Journal of Pharmaceutics*, *392*, 232–240.

Templeton, S. (2005). Management of chronic wounds: The role of silver-containing dressings. *Primary Intention*, *13*, 170–179.

Tian, J., Wong, K. K. Y., Ho, C., Lok, C., Yo, W., Che, H., et al. (2007). Topical delivery of silver nanoparticles promotes wound healing. *ChemMedChem*, *2*, 129–136.

Turner, T. D. (1979). Hospital usage of absorbent dressings. *Pharmaceutical Journal*, *222*, 421–424.

Turner, T. D. (2001). The development of wound management products. In D. L. Krasner, G. T. Rodeheaver, & R. G. Sibbald (Eds.), *Chronic wound care: A clinical source book for healthcare professionals* (3rd ed., vol. 1, pp. 293–310). Wayne, PA: HMP Communications.

Ueno, H., Mori, T., & Fujinaga, T. (2001). Topical formulation and wound healing applications of chitosan. *Advanced Drug Delivery Reviews*, *52*, 105–115.

Wang, C. C., Su, C. H., & Chen, C. C. (2008). Water absorbing and antibacterial properties of N-isopropyl acrylamide grafted and collagen/chitosan immobilized polypropylene nonwoven fabric and its application on wound healing enhancement. *Journal of Biomedical Materials Research Part A*, *84A*, 1006–1017.

Williams & Wilkins. (1997). The science of review. In *Small Animal Internal Medicine*. pp. 100–150.

Wooten, H. L. (1990). *Fiber producer conference. Book of papers* Greenville, SC, (pp. 24–26).

Xu, H. T., Ma, L., Shi, H. F., Gao, C. Y., & Han, C. M. (2007). Chitosan–hyaluronic acid hybrid film as a novel wound dressing: In vitro and in vivo studies. *Polymer for Advanced Technologies*, *18*(11), 869–875.

Yanaga, H., Udoh, Y., Yamauchi, T., Yamamoto, M., Kiyokawa, K., Inoue, Y., et al. (2001). Cryopreserved cultured epidermal allografts achieved early closure of

wounds and reduced scar formation in deep partial-thickness burn wounds (DDB) and split-thickness skin donor sites of pediatric patients. *Burns*, *27*(7), 689–698.
Yang, J. M., & Lin, H. T. (2004). Properties of chitosan containing PP-g-AA-g-NIPAAm bigraft nonwoven fabric for wound dressing. *Journal of Membrane Science*, *243*, 1–7.
Yang, T. H., Chuang, W. Y., Yao, N. K., & Chen, L. W. (1998). Use of a diffusion model for assessing the performance of poly(vinyl alcohol) bioartificial pancreases. *Journal of Biomedical Materials Research*, *40*, 385–391.
Yang, T. H., Yao, N. K., Chang, R. F., & Chen, L. W. (1996). Evaluation of asymmetric poly(vinyl alcohol) membranes for use in artificial islets. *Biomaterials*, *17*, 2139–2145.