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Preparation of silver nanoparticles fabrics against multidrug-resistant bacteria

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HIGHLIGHTS

- AgNPs were synthesized by gamma Co-60 irradiation of Ag^+/chitosan solution.
- AgNPs/peco fabric was prepared by deposition of AgNPs on peco fabric.
- AgNPs/peco fabric was tested as wrapper of patient's bed in hospital.
- AgNPs/peco fabric wrapper inhibited the growth of bacterial strains remarkably.

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ABSTRACT

The silver nanoparticles (AgNPs)/peco fabrics were prepared by immobilization of AgNPs on fabrics in which AgNPs were synthesized by γ-irradiation of the 10 mM $AgNO_3$ chitosan solution at the dose of 17.6 kGy. The AgNPs size has been estimated to be about 11 nm from TEM image. The AgNPs content onto peco fabrics was of 143 ± 6 mg/kg at the initial AgNPs concentration of 100 ppm. The AgNPs colloidal solution was characterized by UV–vis spectroscopy and TEM image. The antibacterial activity of AgNPs/peco fabrics after 60 washings against *Staphylococcus aureus* and *Klebsiella pneumoniae* was found to be over 99%. Effects of AgNPs fabics on multidrug-resistant pathogens from the clinical specimens were also tested.

1. Introduction

Since ancient times, silver in different forms has been widely used as a medicine for treatment of various diseases. At present, the antimicrobial property of silver nanoparticles has been explored in various applications, like water purification, sterile coating for biomedical devices and packaging for food stuffs (Ghosh et al., 2010; González-Sánchez et al., 2015). It has been reported that silver or silver nanoparticles have strong inhibitory and bactericidal effects as well as a broad spectrum of antimicrobial activities for bacteria, fungi and virus (Cho et al., 2005; Yoksan and Chirachanchai, 2009). Compared with other metals, silver exhibits higher toxicity to microorganism while it exhibits lower toxicity to mammalian (Zhao and Sterens, 1998). Antimicrobial effects of silver can be increased by manipulating their size at nanolevel. The bactericidal activity of silver nanoparticles (AgNPs) against the pathogens, the multidrug-resistant (MDR) as well as multidrug-susceptible (MDS) strains of bacteria was studied by some scientists (Rai et al., 2012; Ansari et al., 2011). They proved that the AgNPs are the powerful weapons against the MDR bacteria such as methicillin-resistant *Staphylococcus aureus*, ampicillin-resistant *Pseudomonas aeruginosa*.

Development of antibacterial fabrics based on loading of nanomaterials on the textiles has recently increased significantly. The AgNPs with various nanostructures can be immobilized on the fabrics bringing new properties to the final textile product, especially for antibacterial activity. Many methods have been utilized for synthesis and stabilization of metal nanoparticles (Kannan and Subbalaxmi, 2011; Sáez and Mason, 2009). The modern method of irradiation using gamma or electron beams to produce metal colloidal particles and especially AgNPs, *ex situ* or *in situ*, has been introduced firstly by Belloni's team in the early 1980s and many other authors (Belloni et al., 1982, Platzer et al., 1992, De Cointet

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et al., 1997; El-Batal et al., 2013). The AgNPs were also deposited on fabrics with different processes. The durability of antibacterial substance as AgNPs linked with fabrics is also an important factor. The textile fabrics can be treated with the AgNPs by immersion of fabrics in a produced AgNPs colloidal solution bath (Lee and Jeong, 2005). Besides, the noble metal ions as Ag^+ were reduced to Ag atoms by reductant incorporated into porous fabrics for *in situ* synthesis of AgNPs (Junhui et al., 2003). The AgNPs fabrics were also prepared by other method such as sonochemical coating of AgNPs on textile fabrics (Perelshtein et al., 2008). Additionally, binders or cross-linking polymers were used in the synthesis process of AgNPs fabics to enhance incorporation and fixation of the AgNPs on the fabrics (Montazer et al., 2010; Chen and Chiang, 2008).

In our previous research, we discussed the preparation and characterization of the AgNPs/pure cotton fabrics which were produced by impregnation of fabrics with Ag^+ solution prior to irradiation (Hanh et al., 2014). The goals of this study are: (1) Preparation of colloidal solution of AgNPs by γ-ray irradiation of $AgNO_3$ solution using chitosan which operates both as a stabilizer and a binder. (2) Deposition of AgNPs-chitosan composite on the surface of peco fabric which is composed of 65% polyester and 35% cotton. The durability of AgNPs adhered to fabrics and antibacterial effects *in vitro* and *in vivo* as well as skin irritation test were also investigated after repeated washings.

2. Experimental

2.1. Materials

Peco fabrics (65% polyester and 35% cotton) weighing 115 g/m^2 were provided by VICOTEX Company (Vietnam). Chitosan with a degree of deacetylation to be about 80% and $Mw = 1.06 \times 10^5$ was prepared as reported previously (Hanh et al., 2014). All other chemicals, including silver nitrate ($AgNO_3$), (S)-lactic acid (90%), sodium hydroxide (NaOH) were of reagent grade. Distilled water was used in all experiments.

2.2. Preparation of AgNPs by γ-irradiation of $AgNO_3$ solution

A solution of 10 mM $AgNO_3$ was prepared by dissolving 1.7 g $AgNO_3$ in 1000 ml of 1% chitosan in lactic acid (w/v) and was neutralized by sodium hydroxide to pH 5–6. Then the solution was irradiated in the dose range from 5 to 30 kGy by γ-rays with dose rate of 1.3 kGy/h. The gamma-irradiation dose was determined by using the ethanol-chlorobenzene (ECB) dosimetry system from mean value of absorbed doses of three dosimeters at 30 °C (ASTM International, 2004). The UV–vis spectra of the colloidal AgNPs were recorded on a Jasco V-630 spectrophotometer in the range from 200-600 nm after the solution was diluted 25 times. Transmission electron microscopy (TEM) images were performed with a JEOL JEM-1400 electron microscope at an accelerated voltage of 100 kV.

2.3. Immobilization of AgNPs on peco fabrics

The AgNPs colloidal solution at 10 mM prepared ex situ was diluted to a concentration of 10^{-2} mM before deposition on fabrics. All dry fabric samples were immersed in a colloidal solution bath containing the AgNPs at 10^{-2} mM for 2–3 min and were squeezed to 100% wet pick-up by a rotation axis at a constant pressure. Then the AgNPs fabrics were dried and cured at 120 °C for 2–3 min before rolling AgNPs/peco fabrics product. Fig. 1 shows the preparation process of the AgNPs fabrics. Then, samples were washed in the machine with detergent solution 2 g/l at ambient temperature. Afterwards, samples were rinsed with water and dried by sunlight. A similar procedure was applied for 60 repeated washing cycles. The content of AgNPs was evaluated by inductively coupled plasma atomic emission spectroscopy (ICP-AES), model Optima 5300DV (Perkin Elmer) after 1, 5, 10, 20, 30, 40, 50 and 60 washing cycles. The morphology and distribution of AgNPs on the surface of fabrics were observed using a JSM-6480LV scanning electron microscope was operated at 10 kV and used at 5500 magnification.

2.4. Antibacterial efficacy of AgNPs/peco fabrics

Antibacterial properties of resultant fabrics *in vitro* were verified according to AATCC Test Method 100-2004 against *S. aureus* No. 6538, a Gram-positive organism and *Klebsiella pneumonia* No. 4352, a Gram-negative organism (AATCC Test Method 100-2004, 2009). Test specimens were cut in 4.8 ± 0.1 cm diameters and absorbed 1 ml of inoculums in sterile Petri plates. Then, specimens were placed in the jar contained 100 ml neutralizing solution. Jars were shaked vigorously for 1 min, serial dilutions were made. From each of three suitable dilutions, 0.1 ml liquid was drawn and transferred to nutrient agar, then incubated all plates for 48 h at 37 °C. Percent reduction of bacteria was evaluated by calculating the number of bacteria colonies on agar plates of control and AgNPs fabrics.

The AgNPs fabrics were also sewn into bed sheets to cover the patient's beds in the Intensive Care Unit (I.C.U.) of the General Hospital of Quang Nam Province in Viet Nam for testing *in vivo*. The bacteria which were isolated from the infected sheets at clinic such as *S. aureus, Klebsiella pneumoniae, Acinetobacter spp, Escherichia coli, Enterobacter spp, Proteus, P. aeruginosa, Provindencia spp, Streptococcus pneumoniae* and *Staphylococcus epidermidis* were also observed. Circle samples were cut at the above diameter (4.8 ± 0.1 cm) at the corner of the AgNPs sheet and control fabric. They were then sticked on that AgNPs sheet at place where was predicted most infectious for 24 hours. After that the samples were brought to the Department of Microorganism in hospital for isolation and characterization before evaluation of the

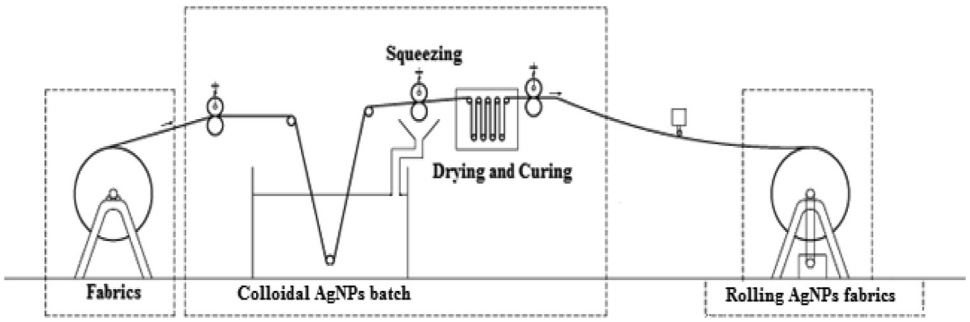

Fig. 1. Schematic illustration for preparation of the AgNPs fabrics.