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Most simple preparation of an inkjet printing of silver nanoparticles on fibrous membrane for water purification: Technological and commercial application

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ABSTRACT

In this study, we describe a new approach of antibacterial water-filter generation which utilized inkjet printing to deposit silver nanoparticles onto an electrospun polyurethane fibrous membrane. It was found that the polyurethane fiber was uniformly fabricated and silver nanoparticles were evenly deposited onto the fibrous strands. As an *in vitro* test, our developed silver-nanoparticle modified polyurethane fibrous membrane showed significant inhibition against four kinds of pathogens that lead to fatal water borne diseases. These results indicate that our approach, which allows for simple, low-cost, mass production of filters, may be useful in the field of water environmental science.

Introduction

For many decades, microbiological contamination of drinking water has been a serious public safety concern. Microbiological contamination dramatically raises the incidence of waterborne diseases [1–3]. Water-borne infectious diseases are one of the main pollutants of drinking water which serve as a global burden especially in developing countries [4–7]. Additionally, the improper handling of waste-water and contamination of drinking water account for approximately 1.7 million deaths per year in the world [8]. For this reason there is a great emphasis amongst scientists and national governments in improving the purification of freshwater so as to reduce these serious illnesses [9].

One means of purifying freshwater is use of a fibrous membrane which allows for removal of microorganisms from the waste-water by filtration [10–12]. Electrospun fibers, which can serve as this fibrous membrane, can be fabricated by electrospinning (ELSP). This manufacturing technique creates membranes with a large surface area and continuous polymer fibers woven throughout the membrane. ELSP is performed through the action of an electrically charged jet of molten polymer solution which allows for the fabrication of membranes from a variety of materials. ELSP also has the advantage of being comparatively simple, cost-effective, and possessing a high harvest rate [13–15]. One drawback to this fibrous membrane is that, outside of being a physical barrier, it does not have any other useful properties. For this reason, some researchers have developed hybrid membranes by incorporating metal nanoparticle in or on the polyurethane fiber strand in order to enhance their antimicrobial activity [16,17]. Polyurethane (PU) is a highly elastomeric, thermoplastic, and water insoluble polymer as well as possesses potent mechanical properties [17,18]. Previously, Jain and Pradeep established that silver nanoparticle (AgNPs) coated onto PU foam can serve as a means to prevent

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bacterial contamination of drinking water [16]. Furthermore, Bjorge et al. demonstrated the production of a polymer membrane containing AgNPs for use as a commercial micro-filter in order to inhibit microbial growth [19]. These studies utilized AgNPs as the antimicrobial agent because AgNPs have previously been used for water treatment applications. Typically they are used to exterminate enormous quantities of microorganisms in waste-water in order to improve human health and environmental safety [20–23]. Unfortunately, these systems are difficult to manufacture in bulk and are not easy to process because of harsh chemical synthesis techniques and cumbersome manufacturing approaches. Therefore, a simpler, more facile approach is necessary.

The inkjet printing system has played a crucial role in the field of electrical engineering for design of functional-substrates and for surface modification. This strategy has several advantages including low-cost, easy access to graphical painting, and being a precise material dispersion technique with non-contact deposition on a variety of substrates [24–26]. Due to these merits, inkjet printing system has been applied in various engineering fields including particle dispersion [27], LED [28], flexible electronics [29], sensors [30], tissue engineering [31], and others. Previously, Nge et al. performed AgNPs inkjet printing on fiber-structured cellulose as a printable substrate in order to generate a flexible paper-based device [32]. Based on these findings, we prepared a PU fibrous membrane via ELSP system followed by inkjet printing of AgNPs directly onto the substrate in order to enhance the antibacterial activity for use as a water purification membrane/filter. In the environmental engineering field, there has not been applied research regarding the use of AgNPs inkjet-printing for water purification. This is the first paper to demonstrate the applicability of silver printing for environmental science and technology as well as demonstrate its application for providing freshwater.

The major goal of this study is to demonstrate the applicability of the manufactured antimicrobial membrane as an effective and convenient filter to eradicate bacteria in waste-water. A schematic illustration of the present study is depicted in Fig. 1. Our developed products were then characterized by field emission-scanning electron microscope (FE-SEM), energy dispersive spectrometer (EDS) with element image mapping, X-ray photoelectron spectroscopy (XPS), X-ray diffraction (XRD), and thermogravimetric analysis (TGA). Furthermore, the antibacterial inhibition *in vitro* test was also performed against four kinds of pathogens including *Escherichia coli* (*E. coli*), *Salmonella enteria* serovar Typhimurium (*S.* Typhimurium), *Shigella flexneri* (*S. flexneri*), *and Shigella sonnei* (*S. sonnei*).

Experimental

Materials

Polyurethane (Bionate 75A) was purchased from Resomer® (Ingelheim, Germany). *N*,*N*-Dimethylformamide (DMF, 99.5%) and tetrahydrofuran (THF, 99.5%) were purchased from JUNSEI (JUNSEI CHEMICAL Co. Ltd, Japan). The Epson stylus C88+ inkjet printer was purchased from Epson (Epson Korea Co., Ltd., Seoul, Korea). Water based silver ink, JS-B25P Metalon®, was purchased from Novacentrix (Austin, TX, USA, formerly Nanotechnologies, Inc.). All chemical solvents/reagents were of analytical grade and used without further purification.

Fabrication of PU nanofiber by ELSP

The preparation of polymer solution for ELSP and the ELSP processing are explained in our previous reports [33–36]. Briefly, in order to prepare the ELSP solution, the PU was dissolved in a mixed solvent system of DMF/THF (v/v = 5:5) with a total concentration of 8% (w/v) solids. After dissolution, ELSP was conducted using the following conditions. The ELSP solution was loaded into a luer-lock syringe equipped with a 20 gauge metal blunt-tip needle. The collector was an aluminum foil covered rotating mandrel. The machine was operated at 20 kV with a flow rate of 1 ml/h. The needle tip-to-collector distance was 15 cm. In order to remove any residual solvent, the obtained membranes were dried overnight under vacuum at room temperature.

Inkjet printing of silver ink onto PU fiber

Prior to printing, the fabricated PU fiber was mounted onto digital printing paper (Doosung Co. Ltd., Korea). The purchased silver ink was injected into a clean cartridge (Epson). After that, inkjet printing was performed directly. The obtained products were dried overnight at room temperature to remove solvents.

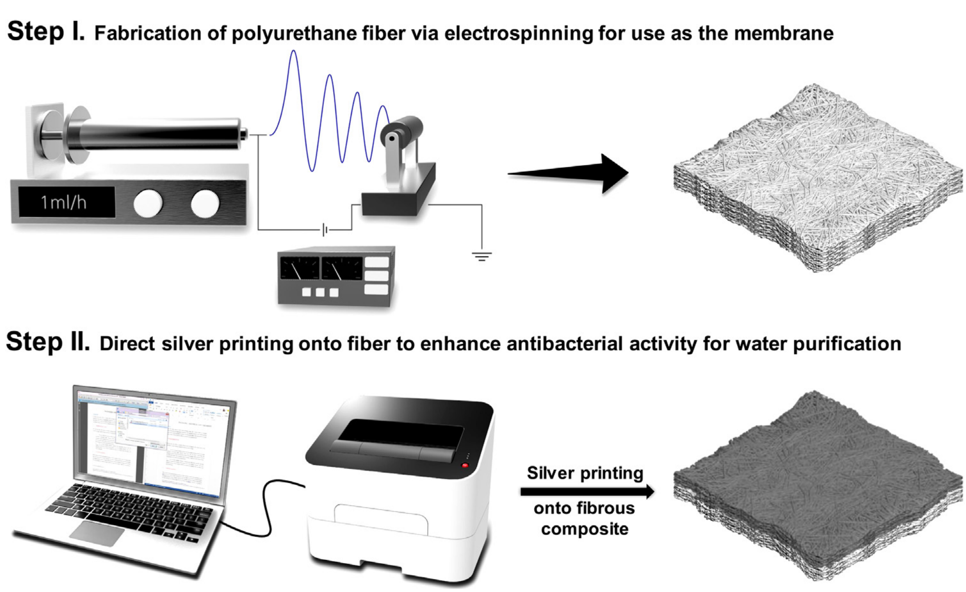

Fig. 1. Schematic illustration of the preparation of antibacterial membrane for water purification.