Journal of Cultural Heritage xxx (2016) xxx–xxx

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Original article

Microbial diversity of pre-Columbian archaeological textiles and the effect of silver nanoparticles misting disinfection

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ARTICLE INFO

Article history:
Received 4 April 2016
Accepted 25 July 2016
Available online xxx

Keywords:
Silver nanoparticles
Microorganisms
Disinfection
Archaeological textiles
SEM-EDS

ABSTRACT

Biodeterioration of archaeological materials contribute to significant economic losses and the destruction of invaluable pieces of cultural heritage. The study materials were 5 pre-Columbian fibres (1250–1450 A.D., Argentina). The microscopic analyses (SEM-EDS) showed that they were made of cotton, sisal and wool, as well as they were contaminated by mineral impurities and dust. So far, no research has been conducted on determining the effectiveness of disinfection with silver nanoparticles (AgNPs) misting of historical textiles. The studies showed that the reduction of microorganism number was between 30.8–99.9%, which depended on the qualitative microbial contamination and its amount. Different AgNPs sensitivity of microorganisms was noted, with the least susceptible being endospore-forming bacteria *Bacillus*, more easily inhibited were bacterial genus *Oceanobacillus*, *Kocuria*, *Paracoccus* and moulds *Cladosporium*, *Penicillium*. AgNPs misting does not adversely influence the pH and chemistry textiles. The presented in this paper disinfection method with AgNPs misting can be used for disinfection of archaeological textiles made of wool, cotton and sisal, as an alternative to the currently available methods.
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1. Research aims

Biodeterioration of historical fabric causes the destruction of priceless cultural heritage. Detailed knowledge of these materials and present microbiota allow for ideal protection. Earlier studies showed that the use of silver nanoparticles (AgNPs) leads to a high protection of textiles against microbial development. AgNPs disinfection did not significantly influence the mechanical and optical parameters of textiles (cotton, flax, wool, silk), even those which were artificially aged. However, so far AgNPs has not been used for the disinfection of historical textiles. Hence, the aims of this paper were to identify archaeological pre-Columbian textiles (1250–1450 A.D.) based on microscopic analysis of their surface; the assessment of the diversity of microorganisms on pre-Columbian textiles; the AgNPs misting disinfection efficiency, the determination of the sensitivity of isolated microorganisms to AgNPs and whether AgNPs misting changes pH and chemistry of disinfected textiles.

2. Introduction

The problem of fabric biodeterioration is often discussed in literature. Biodeterioration not only causes economic losses but in the case of artefacts also an immeasurable loss of cultural heritage. Archaeological fibres, which usually undergo biodeterioration, include wool, cellulose fibres and silk [1,2]. The biodeterioration of textiles leads to a musty odour, change in pH, permanent staining, decrease in strength [3]. Depending on a fibre's origin, different kinds of microorganisms are responsible for their degradation. In animal origin textiles, the carbon and nitrogen source are proteins (e.g. keratin in wool, fibroin and sericin in silk) [4,5]. Wool is mostly degraded by keratinolytic fungi genus: *Acremonium*, *Alternaria*, *Aspergillus*, *Cephalothecium*, *Chaetomium*, *Chrysosporium*, *Dematium*, *Fusarium*, *Microsporum*, *Oospora*, *Penicillium*, *Rhizopus*, *Scolulariopsis*, *Stachybotrys*, *Trichoderma*, *Trichophyton*, *Ulocladium*; as well as bacteria from genera *Alcaligenes*, *Bacillus*, *Proteus*, *Pseudomonas*, *Streptomyces* [5–8]. In the case of plant origin textiles (e.g. cotton, linen) cellulose, hemicellulose, lignin are a food source. Plant origin fabrics are colonized by cellulolytic microorganisms, such as fungi: *Alternaria*,

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http://dx.doi.org/10.1016/j.culher.2016.07.007
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Please cite this article in press as: K. Pietrzak, et al., Microbial diversity of pre-Columbian archaeological textiles and the effect of silver nanoparticles misting disinfection, Journal of Cultural Heritage (2016), http://dx.doi.org/10.1016/j.culher.2016.07.007

Aspergillus, *Aureobasidium*, *Chaetomium*, *Cladosporium*, *Fusarium*, *Mnemoniella*, *Mucor*, *Myrothecium*, *Paeciliomyces*, *Penicillium*, *Rhizopus*, *Stachybotrys*, *Trichoderma*, *Trichotecium*, *Verticillium* and bacteria: *Arthrobacter*, *Bacillus*, *Cellulomonas*, *Cellvibrio*, *Clostridium*, *Cytophaga*, *Microbispora*, *Nocardia*, *Pseudomonas*, *Sporocytophaga Streptomyces* [2,7,9–11].

The protection of cultural heritage from the effects of biodeterioration should consist mainly of appropriate storage of objects. The microclimatic conditions for storage of antique textiles should be stable: temperature about 10 °C, relative air humidity below 50% [12,13]. Any light intensity is not safe for stored item. Recommended 50 lux is a compromise between deterioration and visibility [14,15]. However, if the material has visible signs of microbial growth, it should be immediately isolated from the remaining collection and the appropriate method of disinfection should be applied to protect the material against progressive biodeterioration and people from contact with harmful microorganisms. The choice of the method should be preceded by a detailed research of the material. It must include microscopic and chemical analyses, as well as microbiological procedures. The disinfection should be carried out in the case of the mass contamination of museum collections and prevent the destruction of valuable exhibits. In some cases, conservator may decide that any disinfection method will cause more harm than good, then the object should be kept in RH < 60% to slow down the deterioration. The range of disinfection methods is extensive, chemical methods involve the use of biocides (e.g. ethanol, quaternary ammonium salts, titanium dioxide), gases and vapours (e.g. ethylene oxide, essential oils), while physical factors include: gamma radiation, UV, low or high temperature [16–19]. Each of the methods has a different efficacy, from sterilization to biostatic effect. Most of them were tested for protection of culture heritage objects, but due to many limitations (change the material properties (colour, strength), low effectiveness against spores, harmfulness to humans and the environment) without great success. Hence, the search for a new effective method of disinfection of historical materials is a focus of scientific interest.

The antimicrobial properties of silver have been known for centuries. Due to the wide range of properties including antimicrobial it is widespread and used in e.g. medicine, chemistry, electronics, papermaking, in everyday products such as underwear, air filters, coatings in refrigerators, washing machines [20–22].

Previous studies have shown that silver nanoparticles in the form of a mist may be used for disinfection of historical materials [23]. We have carried out model studies which allowed for the optimization of the process in order to achieve the highest antimicrobial efficiency [24–26]. The disinfection process is carried out in a closed chamber (safe for both the operator and environment) (Fig. 1). The detailed description of process parameters was published by Gutarowska et al. [23]. The obtained results were promising and material studies (also artificial ageing) showed that this process does not substantially affect the strength (elongation at break, tensile and tear indices, breaking strength) and colour parameters (CIELab and whiteness) for textiles (wool, silk, cotton, flax), papers (5 different types), wood (pine, oak, beech) and leather [23,26]. An additional advantage of this method is the protection for the future (applied AgNPs remain on the surface), as compared to the short-term methods [26]. The best antimicrobial results were obtained for textiles (linen and silk) and groundwood paper (mean reduction equalled to 69–92%) and it was higher for moulds than bacteria [23]. The disinfection of historical objects (19th–20th century) resulted in satisfactory reduction of 99.9% on wood and paper maps and lower on painting canvas and parchment: 68–80% [25]. In addition, there was no threat to the employee when working with the disinfection chamber. The level of AgNPs in the air was 0.22 mg/m^3 and decreased over two-fold after chamber airing [26]. The noted values are lower than any limitations for nanoparticles suggested by the National Institute for Occupational Safety and Health (NIOSH) [27,28]. In view of the previously obtained results, in the presented paper AgNPs misting was applied for the first time to archaeological textile objects – the fragments of the pre-Columbian (1250–1450 A.D.) fabrics La Plata Museum in Argentina.

Fig. 1. Disinfection chamber for sliver nanoparticle misting.

Table 1
Characteristics of tested fibre samples.

No.	Type		Origin
1	Archaeological textile	Cotton	1250–1450 AD Puna Argentina, Santa Rosa de Tastil (Argentina)
2		Sisal	
3		Wool	
4		Wool	
5		Wool	
6	Animal hair	*Lama pacos*	Municipal Zoological Garden in Lodz (Poland)
7		*Lama guanicoe*	
8		*Vicugna vicugna*	

3. Materials and methods

3.1. Textile samples

The pre-Columbian archaeological textiles (5 samples, Nos. 1–5) were deposited in Deposit 25 at La Plata Museum (Argentina) (Table 1, Fig. 2). According to Museum data, all textiles were made of wool (analysis showed that two are made of cotton and sisal). For morphological analysis of archaeological fibres, as a comparison, the animal hair of three camelids was tested: *Lama pacos* (alpaca), *Lama guanicoe* (guanaco) and *Vicugna vicugna* (vicugna) (3 samples, Nos. 6–8) (obtained from the Municipal Zoological Garden in Lodz, Poland) (Table 1).

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