Journal of Photochemistry & Photobiology, A: Chemistry 411 (2021) 113200

Contents lists available at ScienceDirect

Journal of Photochemistry & Photobiology, A: Chemistry

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

Enhanced photo-ablation effect of positively charged phthalocyanines-detonation nanodiamonds nanoplatforms for the suppression of *Staphylococcus aureus* and *Escherichia coli* planktonic cells and biofilms

Yolande Ikala Openda, Tebello Nyokong *

Institute for Nanotechnology Innovation, Department of Chemistry, Rhodes University, Makhanda 6140, South Africa

ARTICLE INFO

Keywords:
Detonation nanodiamonds
Chalcone phthalocyanines
Biofilms
Planktonic
Photodynamic antimicrobial therapy

ABSTRACT

Photodynamic antimicrobial therapy (PACT) is a powerful technic recommended to eliminate life-threatening pathogens that cause localized and superficial infections as pathogens cannot develop resistance to it. For this reason, new positively charged chalcone substituted zinc (**3a**) and indium (**4a**) metalated phthalocyanines (Pcs) were synthesized and were π-π interacted with detonation nanodiamonds (DNDs) nanoparticles to form new water soluble nanoplatfoms **3a**@DNDs and **4a**@DNDs. The conjugates generated high singlet oxygen quantum yields (Φ_Δ) in water (1% DMSO, used for PACT studies) with values of 0.46 and 0.47 for **3a**@DNDs and **4a**@DNDs, respectively. Hence, they were tested for PACT against biofilms of *S. aureus* and *E. coli*, as well as their planktonic cells. The quaternized Pcs alone **3a** and **4a** as well as their nanoconjugates **3a**@DNDs and **4a**@DNDs were effective PACT agents with $\log_{10}$ CFU > 9 for *E. coli* and *S. aureus*. The quaternized derivatives were found to have higher ability to completely suppress both planktonic and biofilms of *S. aureus* and *E. coli in vitro*. Therefore, they could be used as appropriate photosensitive agents.

1. Introduction

Up to 60 % of severe infection cases leading to deaths globally are attributed to bacterial biofilms. Free pathogenic bacteria cells that adhere to a living or inert surface tend to form a bacterial biofilm structure [1,2]. It is much more difficult to eradicate pathogenic bacteria living within a biofilm as they easily develop resistance to the available antibiotic drugs and treatments [3–5]. Additionally, bacteria in biofilms can tolerate 10–1000 times higher dosage of antibiotics than their planktonic forms (free bacteria cells) [6]. Therefore, the major challenge remain to develop new antibiofilm approaches to fight against bacteria biofilms, either by biofilm structure disruption or suppression of biofilm [7]. Amongst many techniques based on the generation of singlet oxygen, there is photodynamic antimicrobial chemotherapy (PACT).

The photodynamic effect consist of a non-toxic photosensitizer (PS) that is activated by visible light of appropriate wavelength in the presence of oxygen leading to the production of reactive oxygen species (ROS) including singlet oxygen that can cause cell death [8,9]. Concentration, nature and spectral properties of a PS are crucial in the efficacy of PACT [8,10]. PACT does not target a single site in bacteria, unlike conventional antibiotics. ROS target various bacterial cell structures and different metabolic pathways [11]. Thus, bacteria do not readily develop resistance to PACT [12].

Several studies have also indicated that the photoinactivation of Gram-negative bacteria (*i.e. E. coli*) is quite challenging because of the complexity in the composition of their cell wall as compared to Gram-positive bacteria (*i.e. S. aureus*) [13]. Therefore, it is agreed that a good PS should also combine characteristics such as hydrophilicity and positive charge(s) for attachment towards negatively charged bacterial cell walls, but also to prevent aggregation in aqueous medium and improve cell uptake [14–17]. Metallophthalocyanines (MPcs) are known PACT photosensitizers for planktonic cells and biofilms [18–20]. Increasing the number of positive charges on the substituents enhances the extent of phthalocyanine binding to gram-negative bacteria such as *E. coli* [21]. Thus, the development of new polycationic phthalocyanines is needed [22] as they show successful PACT activities and high affinity to the bacteria cells.

Hence in this work, we synthesize new pyridine chalcone

* Corresponding author.
E-mail address: t.nyokong@ru.ac.za (T. Nyokong).

https://doi.org/10.1016/j.jphotochem.2021.113200
Received 14 September 2020; Received in revised form 1 February 2021; Accepted 6 February 2021
Available online 12 February 2021