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Promising photodynamic antimicrobial activity of polyimine substituted zinc phthalocyanine and its polycationic derivative when conjugated to nitrogen, sulfur, co-doped graphene quantum dots against *Staphylococcus aureus*

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ABSTRACT

Antimicrobial resistance is a most important problem facing the treatment of infectious diseases. Antimicrobial photodynamic therapy is an alternative treatment strategy, considered to be cost-effective and feasible. For this purpose, octa-imine substituted ZnPc (**3**) have been prepared and conjugated to nitrogen, sulfur co-doped graphene quantum dots (N,S-GQDs) through π-π stacking. The photophysical and photochemical properties of Pc alone and and Pc-conjugated to the GQD nanomaterial such as absorption, fluorescence, fluorescence life time, singlet oxygen quantum yields, triplet state quantum yields and exited state lifetimes were investigated in solutions before *in vitro* cell studies. The PACT activity of prepared structures was investigated against Gram-positive (*Staphylococcus aureus*). Our results suggest that the in the case of conjugation of zinc Pc to N,S-GQDs, photodynamic inactivation increased with the 100 % reduction percentage

1. Introduction

The work in the domain of antimicrobials is one of the most important health-related issues worldwide. Pathogenic microorganisms widely exist everywhere such as in the air, on different surfaces and in food [1]. Unfortunately, antibiotics used for public health to inactivate the microorganisms are not always effective due to the resistance of bacteria to current antibiotics [2]. Moreover, some conventional methods for disinfection of surfaces and foods such as ultraviolet (UV) irradiation and thermotherapy require excessive amounts of energy [3, 4]. These drawbacks limit the applicability of the current methods.

The need to overcome these deficiencies has stimulated scientists to develop alternative treatments and antimicrobial reagents towards microbial infections. Recently, research efforts have been addressed to light-based technology called photodynamic therapy (PDT) [5]. PDT was originally applied as an anticancer method and is currently clinically utilized in the treatment of cancer [6].

The photodynamic inactivation process is based on the use of visible light in combination with photoactive molecule called as photosensitizer (PS) in the presence of molecular oxygen in and around cells [7]. After the PSs are exposed to illumination, they are excited to the singlet state and can switch between systems to transition to the triple state (^{3}PS*) where they form singlet oxygen which is toxic for the biomolecules [8].

In this context, photodynamic antimicrobial therapy (PACT) has been recognized as a bright approach to efficiently destroy microorganisms and has shown good results [9,10]. The photosensitizer is administered and selectively accumulates in the microorganisms, followed by irradiation with visible light. The formed toxic oxygen species cause the cell inactivation and death through selective destruction of the target microorganism [11]. It is obvious that it is difficult for bacteria to develop resistance against PACT.

The PSs play a precious role in PACT since the efficacy of the photodynamic action depends on the efficiency of singlet oxygen generation by the PSs. So far, some kinds of photosensitizing drugs including porphyrins, chlorins, bacteriochlorins with different molecular frameworks have been tested in vitro and in vivo against pathogens [12–14].

Phthalocyanines (Pcs) are valuable photosensitizer because they have the desired physicochemical properties. They can form long-lived triplet excited states, consequently they show high singlet oxygen production as well as having intracellular localization [15].

The PACT activity of phthalocyanines has been studied against both

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