Materials Science and Engineering C 74 (2017) 568–581

Contents lists available at ScienceDirect

Materials Science and Engineering C

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

Anti-bacterial activity of graphene oxide as a new weapon nanomaterial to combat multidrug-resistance bacteria

Mohammadreza Yousefi [a], Mehdi Dadashpour [b,1], Maryam Hejazi [c], Mohammad Hasanzadeh [d,*], Behzad Behnam [e], Miguel de la Guardia [f], Nasrin Shadjou [g,h], Ahad Mokhtarzadeh [i,**]

[a] Department of Biotechnology, Higher Education Institute of Rab-Rashid, Tabriz, Iran
[b] Department of Medical Biotechnology, Faculty of Advance Medical Science, Tabriz University of Medical Science, Tabriz, Iran
[c] School of Medicine, Gonabad University of Medical Sciences, Gonabad, Iran
[d] Drug Applied Research Center, Tabriz University of Medical Sciences, Tabriz 51664, Iran
[e] Pharmaceutics Research Center, Institute of Neuropharmacology, Kerman University of Medical Sciences, Kerman, Iran
[f] Department of Analytical Chemistry, University of Valencia, Dr. Moliner 50, 46100 Burjassot, Valencia, Spain
[g] Department of Nanochemistry, Nano Technology Research Center, Urmia University, Urmia, Iran
[h] Department of Nanochemistry, Faculty of Science, Urmia University, Urmia, Iran
[i] Research Center for Pharmaceutical Nanotechnology, Tabriz University of Medical Sciences, Tabriz, Iran

ARTICLE INFO

Article history:
Received 13 August 2016
Received in revised form 10 November 2016
Accepted 16 December 2016
Available online 5 January 2017

Keywords:
Graphene oxide
Multidrug-resistant
Nanocomposites
Antimicrobial
Nanomaterial

ABSTRACT

Antibiotic resistance in microbial pathogens has become a serious health problem in the world. The increasing spread of hospital acquired infections especially in immunocompromised and cancer patients caused by multi-drug-resistant (MDR) microbial pathogens is restricting the choices for impressive antibiotic therapy. So many efforts have been made to develop new compounds with antimicrobial activity. In recent years, nanoparticles, particularly graphene oxide (GO) nanoparticles have found many applications in various fields, including anti-bacterial action, pathogens bio detection, cancer therapy, and drug and gene delivery. The use of graphene oxide as an antibacterial agent for the treatment of infections with multidrug resistance is growing due to the unique physicochemical properties as wide surface area, excellent electrical and thermal conductivity, and bio-compatibility. To reduce toxicity and increase the efficiency of graphene oxide as an antimicrobial agent, different surface modification and functionalization with inorganic nanostructures, biomolecules and polymers were developed. In this review article, we give our overview of the progress made on the graphene oxide nanocomposites as a new generation of antimicrobial agents.

Contents

* Corresponding author.
** Correspondence to: A. Mokhtarzadeh, Department of Biotechnology, Higher Education Institute of Rab-Rashid, Tabriz, Iran.
E-mail addresses: hasanzadehm@tbzmed.ac.ir, mhmmd_hasanzadeh@yahoo.com (M. Hasanzadeh), Mokhtarzadeha891@mums.ac.ir (A. Mokhtarzadeh).
[1] Co-first author.

http://dx.doi.org/10.1016/j.msec.2016.12.125
0928-4931/

1. Introduction

Classical antibiotic drugs have reduced their capacity in front of widespread infectious diseases and become needed for many medical interventions. Antibiotics paved the way for unheard medical and societal developments, and are today essential in all health systems [1,2]. In recent years, multi drug resistance has widely increased among many species of pathogenic bacteria in worldwide and led to the most commonly antibiotics no longer effective in controlling of infectious diseases and thus created concern and challenge in the healthcare sector [3]. So, the development of new antibacterial systems in front of drug resistant pathogens is a serious threat for the successful treatment of microbial disease [4–6].

Multidrug-resistant organisms (MDR) were lately named as the 'ESKAPE' pathogens (*Enterococcus faecium*, *Staphylococcus aureus*, *Klebsiella pneumoniae*, *Acinetobacter baumannii*, *Pseudomonas aeruginosa* and *Enterobacter* spp.), denoting their escape from the effects of antibacterial agents or the non-existence of new active antibiotics [7]. The reasons of antibiotic resistance are complex and include human behavior at many levels of society from which the consequences affect everybody in the world [8]. Many attempts have been made to explain the antibiotic resistance and the interventions needed to meet the challenge [9]. The rising resistance of bacteria and fungi to classical antibiotics have created massive clinical problems in immunocompromised, AIDS and cancer patients [10]. In addition, the identification and treatment of antibiotic-resistant microorganisms are difficult and costly [10,11]. Furthermore complications associated with antibiotic-resistant bacterial infections, provide a high morbidity and mortality rate [12]. For example, annually in the United States, at least 2 million people are infected by antibiotic-resistant bacteria and every year, at least 23,000 people lose their lives due to these infections.

Resistance to antibiotics could be intrinsic or acquired and may be transferred horizontally or vertically [13]. There are several mechanisms of antibiotic resistance such as inhibition of drug uptake, enzymatic modification of antibiotics, alteration of target molecules, transformation, drug sequestration and active efflux out of the cytoplasm [4,9,14] as it has been summarized in (Fig. 1).

So the emergence of antimicrobial resistance is creating challenges that require a multidisciplinary approach including: (i) biomedical innovation, (ii) precise control of antibiotic consumption and antimicrobial-resistance rates, (iii) inhibition of health-care-associated infections and spread of multidrug-resistant (MDR) bacteria and environmental propagation, (iv) rapid microbiological diagnosis, and (v) elimination of clinical and veterinary misuse [15,16].

According to the guidelines listed above, a critical mass of researches focused on the development of new antimicrobial agents or formulations of common antibacterial compounds to combat pathogenic bacteria [17]. So, a variety of new antimicrobial drugs for the treatment of resistant pathogens have been synthesized, being an important group that based on the use of nanoparticle-based materials [18,19].

Antimicrobial nanoparticles (NPs) compared to conventional antibiotics have some obvious advantages, including low toxicity, overcome resistance and reduce cost [20]. Today, by the emergence of nanotechnology, many nanomaterials (NMs) with antibacterial properties have been produced to fill the gap antibiotic treatment failure [21]. Nanoparticles with antibacterial properties include: iron oxide (Fe_3O_4), zinc oxide (ZnO) [22], copper oxide (CuO) [23],titanium oxide (TiO_2) [24], silver (Ag) [25], Magnesium oxide (MgO) [26], graphene oxide (GO)

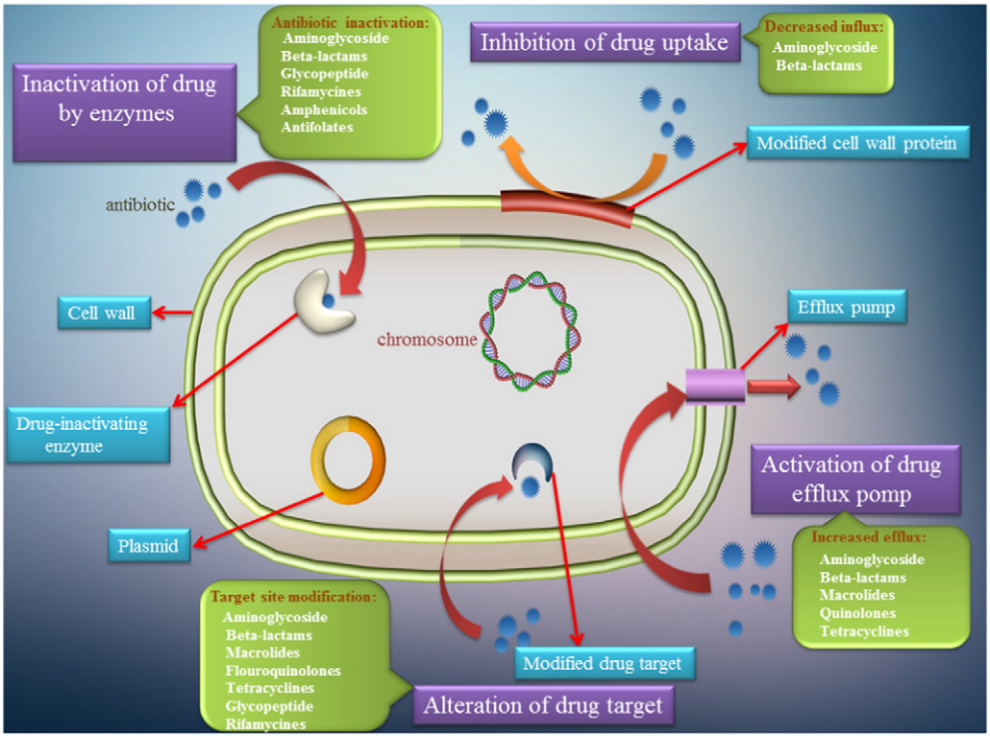

Fig. 1. Mechanism involved in the development of cell antibiotic resistance.