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An N-halamine-based rechargeable antimicrobial and biofilm controlling polyurethane

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ABSTRACT

An N-halamine precursor, 5,5-dimethylhydantoin (DMH), was covalently linked to the surface of polyurethane (PU) with 1,6-hexamethylene diisocyanate (HDI) as the coupling agent. The reaction pathways were investigated using propyl isocyanate (PI) as a model compound. The results suggested that the imide and amide groups of DMH have very similar reactivities toward the isocyanate groups on PU surfaces activated with HDI. After bleach treatment the covalently bound DMH moieties were transformed into N-halamines. The new N-halamine-based PU provided potent antimicrobial effects against *Staphylococcus aureus* (Gram-positive bacterium), *Escherichia coli* (Gram-negative bacterium), methicillin-resistant *Staphylococcus aureus* (MRSA, drug-resistant Gram-positive bacterium), vancomycin-resistant *Enterococcus faecium* (VRE, drug-resistant Gram-positive bacterium), and *Candida albicans* (fungus), and successfully prevented bacterial and fungal biofilm formation. The antimicrobial and biofilm controlling effects were stable for longer than 6 months under normal storage in open air. Furthermore, if the functions were lost due to prolonged use they could be recharged by another chlorination treatment. The recharging could be repeated as needed to achieve long-term protection against microbial contamination and biofilm formation.

1. Introduction

Thanks to its wide availability, low cost, ease of fabrication, and excellent physical and biological properties polyurethane (PU) has become one of the most versatile polymers in medical, dental, industrial, institutional, and environmental applications [1–3]. Unfortunately, like most conventional polymers, the PU surface is susceptible to contamination by microorganisms, which can act as sources of cross-contamination and cross-infection [4–6]. Moreover, adherent microbial species can secrete "slimes" (extracellular polymeric substances or EPS) that attach them firmly to the material surfaces, resulting in irreversible adhesion and biofilm formation [7–9]. Once formed, biofilms are very difficult to destroy. Protected by the EPS, microbes living in a biofilm are up to 1000 times more resistant to disinfection, causing serious problems, including device-related infections, healthcare-acquired infections, waterborne/foodborne illnesses, corrosion, blockage of filters, etc.

Consequently, there has been a growing interest in the development of antimicrobial polymers, including antimicrobial PU, to solve these problems. The majority of reported antimicrobial PU was prepared by either physically mixing antimicrobial agents (e.g. antibiotics, metal ions, quaternary ammonium salts, iodine, etc.) into or covalently binding the antimicrobial agents onto the target polymers [11–14]. Nonetheless, since microbial contamination and biofilm formation mainly occur on polymer surfaces, it could be advantageous to utilize surface modification to impart the desired antimicrobial effects without causing bulk structural/property changes in the polymers [10,15]. The research interest of this laboratory focuses on N-halamine-based antimicrobial and biofilm controlling polymers. N-Halamines are compounds containing one or more nitrogen–halogen covalent bonds. N-Halamines have antimicrobial efficacies similar to that of hypochlorite bleach, one of the most widely used disinfectants, but they are more stable, less corrosive, and have much less tendency to generate halogenated hydrocarbons. Therefore, N-halamines have found wide applications as food and water disinfectants [16,17]. Moreover, once N-halamine structures are covalently linked to the backbones of ordinary polymers the antimicrobial effects can be retained and the resulting polymers are transformed into antimicrobial polymers [18–23].

Building on these results, in the current study we report a strategy to covalently bind an N-halamine precursor, 5,5-dimethylhydantoin (DMH), onto the PU surface using hexamethylene diisocyanate (HDI) as a coupling agent. The bound DMH moieties on the PU surface are transformed into N-halamines through a simple bleach treatment, leading to potent antimicrobial and biofilm

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