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Mini Review

Intelligence Antibacterial Surfaces Based on Stimulus Response

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Abstract

Intelligence antimicrobial strategy with bacterial release function can solve the problem of accumulation of dead bacteria and thus biofouling. Many stimulus-responsive intelligence antimicrobial surfaces have been developed based on this strategy, such as responding to stimuli such as pH, temperature, salt solution and light. Sugar-responsive antimicrobial strategies have been developed to achieve gentler intelligence antimicrobial surfaces, mainly based on Phenylboronic Acid (PBA) and boronate ester bonds between various diol containing biomolecules trigger the bactericidal activity of the surface, which is then treated with a sugar solution to release bacterial debris. In addition, a multi-functional and multi-responsive intelligent antibacterial surface can be prepared by combining sugar stimulation with other stimuli. It provides the foundation for realizing the long-term efficient and renewable antibacterial target.

Keywords: Biofilms; Adherent bacteria; Antifouling; Bactericidal function; Antimicrobial

Introduction

Bacteria adhering to the surface of medical devices can subsequently generate biofilms [1] that can cause infections and pose a significant threat to patient health [2]. Many intelligence antimicrobial strategies have been developed to prevent bacterial adhesion [3,4] and kill adherent bacteria [5,6], but they all have limitations in that surfaces with a single antifouling and bactericidal function cannot achieve the goal of regeneration and long-term use. The killed bacteria will gather on the surface of the bacteria, and with the continuous maintenance of bactericidal activity, the dead bacteria and debris will gradually cover the surface, thus preventing the intelligence surface from continuously playing the antifouling and bactericidal role. Stimulus-responsive surfaces are a new type of intelligence surface in which the physicochemical properties as well as the performance of the surface change significantly in response to external stimuli [7].

Based on the need for practical applications, renewable intelligence antimicrobial surfaces with bacterial release have gained widespread attention, and many functional polymers that respond to environmental stimuli and trigger bacterial release have been applied to prepare antimicrobial surfaces. For example, poly (methacrylic acid) (PMAA) that responds to pH shift [8], temperature-responsive poly(N-isopropylacrylamide) (PNIPAAm) that is very widely used [9], amphoteric polymers that respond to salt solution changes [10,11], and azo molecules that respond to light stimulation [12], etc. They are usually used in combination with biocides to undergo chemical structure changes or conformational transitions in response to stimulation by external environmental changes, thus achieving the function of releasing killed bacteria and other debris. Although the active intelligence surfaces prepared from the stimuli-responsive polymers described above have efficient bactericidal and release capabilities, the widely varying pH and temperature during preparation as well as the UV light and other chemical reagents used can have some detrimental effects on the organisms, so a safer stimuli-responsive intelligence antimicrobial surface for long-term use needs to be sought.

Sugar-Responsive Intelligence Antimicrobial Surface

The sugar response is a non-invasive and gentle response to the organism, mainly through dynamic boronic ester bonding between PBA [13,14] and diol-containing biomolecules, which plays a role in the recognition and separation of molecules on intelligence antimicrobial surfaces (Figure 1a). Chen et al. combined the diol structure in β-cyclodextrin (β-CD) [15] with PBA to prepare a sugar-responsive intelligence surface with switchable activity. β-CD is responsible for recognizing, capturing and killing the bacteria attached to the surface, thus "turning on" the bioactivity of the surface (Figure 1b) while subsequent treatment with fructose solution activates the release of dead bacteria from the surface, which can reach 80% (Figure 1c-d), while "turning off" the bioactivity of the surface. The whole process is non-invasive to the organism, non-cytotoxic, non-resistant and has excellent biocompatibility [16].

In addition, the sugar response can act synergistically with other stimulus responses to avoid the limitations of a single response. They prepared a multifunctional intelligence surface by combining sugar content, PH and temperature response (Figure 1e), using interactions between borate ester bonds in PBA and molecules containing diol structures to trigger the PH response and sugar response functions, and adding the temperature response material PNIPAAm, which can individually or synergistically modulate the bacterial adhesion, killing and release functions of the surface (Figure 1f-g). The intelligence surface can reversibly switch between the functions of killing bacteria and releasing attached proteins, bacteria and other debris, and the multi-stimulus-responsive intelligence antimicrobial surface is more in line with the living environment in which real organisms live, and its bactericidal and release functions are significantly enhanced compared to single-response stimuli, while the regenerative capacity and long-term antimicrobial ability of the intelligence surface will be enhanced [17].

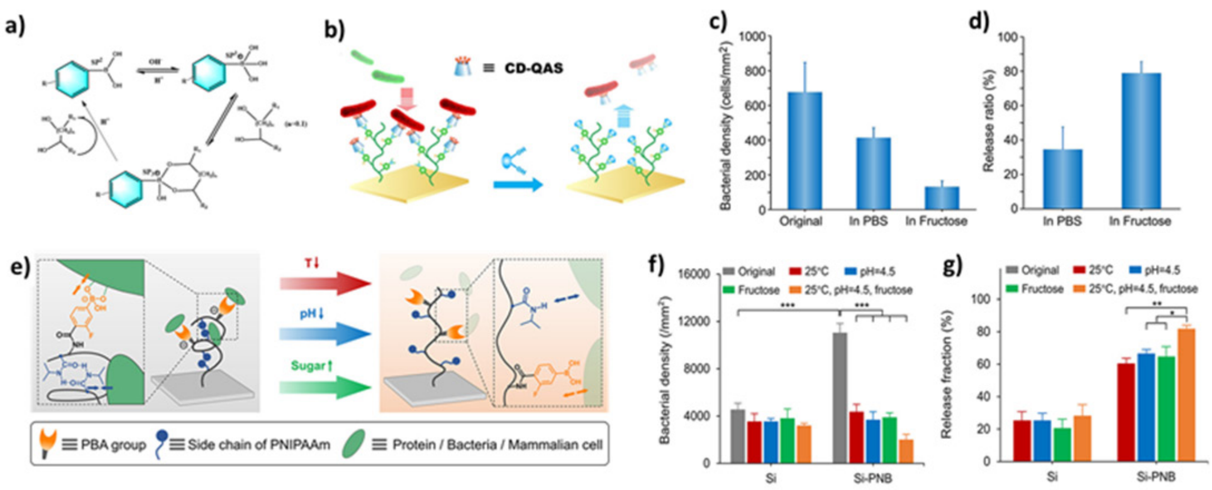

Figure 1: a) Schematic illustration of the interaction between boronic acids and cis-diol-containing compounds. b) Schematic illustration of sugar-triggered bacterial release from the Au-PBH/CD-QAS surface. c)Density of bacteria on different surfaces before and after treatment with PBS or fructose solution (60 mM in PBS). d)Corresponding bacterial release ratios. Error bars represent the standard deviation of the mean(n = 3). e) Schematic illustration of a multistimulus responsive biointerface with switchable bioadhesion. f) Number density of initially attached E. coli and E. coli remaining on the unmodified Si and Si-PNB surfaces after application of different stimuli. g) The corresponding release fractions are summarized in panel [16,17].

Summary

Intelligence antimicrobial surfaces based on sugar stimulus response provide a theoretical basis for a safe and gentle intelligence antimicrobial strategy that not only circumvents various adverse effects due to bacterial accumulation but also reduces the side effects of other stimuli on the organism. But now this intelligence surface is still in the early experimental research stage, for the real application and achieve industrial production there is still a certain distance. On the one hand its germicidal release ability cannot be achieved for a long time, often can withstand several cycles of reuse, which is not possible for long-term use in practical applications; on the other hand the bacterial environment faced by living organisms is complex and variable, unlike the specific few bacteria used in the experimental process, lacking the ability to kill a broad spectrum of bacteria. Although this intelligence antimicrobial surface still lacks certain applicability, it provides new ideas for the preparation of renewable intelligence antimicrobial surfaces, adding more possibilities for extending the life of medical devices to enhance their durability.

References

1. Hathroubi S, Mekni MA, Domenico P, Nguyen D, Jacques M (2017) Biofilms: Microbial shelters against antibiotics. Microb Drug Resist 23(2): 147-156.

2. Zander ZK, Becker ML (2018) Antimicrobial and antifouling strategies for polymeric medical devices. ACS Macro Lett 7(1): 16-25.
3. Ma W, Ding Y, Zhang M, Gao S, Li Y, et al. (2020) Nature-inspired chemistry toward hierarchical superhydrophobic, antibacterial and biocompatible nanofibrous membranes for effective UV-shielding, self-cleaning and oil-water separation. J Hazard Mater 384: 121476.
4. Lin J, Hu J, Wang W, Liu K, Zhou C, et al. (2021) Thermo and light-responsive strategies of smart titanium-containing composite material surface for enhancing bacterially anti-adhesive property. Chemical Engineering Journal 407: 125783.
5. Wu Y, Wang J, Li L, Fei X, Xu L, et al. (2021) A novel hydrogel with self-healing property and bactericidal activity. Journal of Colloid and Interface Science 584: 484-494.
6. Rajavel K, Shen S, Ke T, Lin D (2021) Photocatalytic and bactericidal properties of MXene-derived graphitic carbon-supported TiO2 nanoparticles. Applied Surface Science 538: 148083.
7. Tokarev I, Motornov M, Minko S (2009) Molecular-engineered stimuli-responsive thin polymer film: A platform for the development of integrated multifunctional intelligent materials. Journal of Materials Chemistry 19(38): 6932-6948.
8. Wei T, Yu Q, Zhan W, Chen H (2016) A smart antibacterial surface for the on-demand killing and releasing of bacteria. Adv Healthc Mater 5(4): 449-56.
9. Nagase K, Yamato M, Kanazawa H, Okano T (2018) Poly(N-isopropylacrylamide)-based thermoresponsive surfaces provide new types of biomedical applications. Biomaterials 153: 27-48.
10. Liu Z, Yi Y, Song L, Chen Y, Tian L, et al. (2022) Biocompatible mechano-bactericidal nanopatterned surfaces with salt-responsive bacterial release. Acta Biomaterialia 141: 198-208.
11. Xiao S, Zhao Y, Jin S, He Z, Duan G, et al. (2022) Regenerable bacterial killing–releasing ultrathin smart hydrogel surfaces modified with zwitterionic polymer brushes. e-Polymers 22(1): 719-732.
12. Zhan W, Wei T, Yu Q, Chen H (2018) Fabrication of supramolecular bioactive surfaces via beta-cyclodextrin-based host-guest interactions. ACS Appl Mater Interfaces 10(43): 36585-36601.
13. Li D, Chen Y, Liu Z (2015) Boronate affinity materials for separation and molecular recognition: Structure, properties and applications. Chem Soc Rev 44(22): 8097-8123.
14. Brooks WL, Sumerlin BS (2016) Synthesis and applications of boronic acid-containing polymers: From materials to medicine. Chem Rev 116(3): 1375-1397.
15. Liu Y, Qin A, Chen X, Shen XY, Tong L, et al. (2011) Specific recognition of β-cyclodextrin by a tetraphenylethene luminogen through a cooperative boronic acid/diol interaction. Chemistry-A European Journal 17(52): 14736-14740.
16. Zhan W, Qu Y, Wei T, Hu C, Pan Y, et al. (2018) Sweet switch: Sugar-responsive bioactive surfaces based on dynamic covalent bonding. ACS Appl Mater Interfaces 10(13): 10647-10655.
17. Zhou Y, Zheng Y, Wei T, Qu Y, Wang Y, et al. (2020) Multistimulus responsive biointerfaces with switchable bioadhesion and surface functions. Acs Applied Materials & Interfaces 12(5): 5447-5455.

