The antibacterial surface based on polymer brush

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Abstract. The application of biomedical materials suffers from bacterial infection because of the adherent bacteria would form a biofilm on the surface of the material and cause a pathogenic infection, it creates huge challenges especially in healthcare, such as surgical equipment in hospitals and medical implants. In order to prevent the adhesion of nonspecific bacteria, the polymer brush has been scouted and become a reliable way which has controllable brush thickness, strong mechanical stability and further modification potential. In this paper, we summarized the recent progress of antibacterial surface based on polymer brush. The preparation method of surface polymeric brush including the “grafting to” and “grafting from” method is expounded in detail. According to the mechanism of bacterial infection, there are three strategies to settle this problem. The first one is regulating the adhesion behavior of bacteria on the surface of materials to block the first step of infection. Then sterilization strategy using bactericide to kill bacteria adhering to the surface of the material directly. And the anti-adhesion bactericidal combination strategy has the advantage of sterilizing for a long time which can make up the shortcomings of the above two methods. However, it is still in the early stages of fully solving the problem, the long-lasting, efficient, and environmentally friendly antibacterial composite surfaces is in urgent need.

1. Introduction
Bacterial infection is the cause of many diseases in humans, such as corneal lesions caused by proteins on the surface of contact lenses and conjunctivitis caused by excessive bacteria in swimming pools. Bacteria are widely distributed in nature, and all kinds of materials that contact with human beings are attached to bacteria. Public places, such as schools and public transports, are densely populated and highly mobile, which are more likely to lead to the spread and epidemic of germs. In medical areas, patients with infectious diseases may be transported to the surrounding environment at any time, causing the hospital to become a place where pathogenic microorganisms gather. People in this environment are always at risk of bacterial infection[1]. After the medical instruments are implanted in the human body, the bacteria on the surface of the medical instruments are the most important cause of the infection in the hospital. It brings serious economic loss to the patient, even causes disability and endangers life safety[2]. When these exogenous economic substances are implanted into an organism, the surface of the implant absorbs bacteria and eventually accumulates to form a biofilm, leading to serious infection complications. The formation of biofilm will make it difficult for sterilizing drugs to act on the surface of materials and reduce the aging of materials. Therefore, it is of great importance to develop antibacterial surfaces in materials science contributing to human health. Antibacterial surfaces are widely used in medical devices. They are substances that prevent bacteria from sticking and growing on
the surface of materials. However, the biofilm caused by bacteria adhesion on the surface of biomaterials is a major challenge for the medical industry[3]. Bacteria first adhere to the surface of the substance, and then communicate with each other through signal molecules, attracting similar bacteria. When the concentration of the signal molecules rises, some genes in the bacteria are activated and secrete the protein components that make up the extracellular matrix to form a complete biofilm structure[4,5]. Once the biofilm is formed, bacteria in the membrane is resistant to antibiotics and other bactericidal drugs and the ability to prevent the immune system from being removed will be greatly enhanced, thus causing persistent bacterial infection. In order to enable the material, acquire the antibacterial properties, it is necessary to construct the antibacterial surface according to the mechanism of bacterial infection. The methods are mainly about antibacterial adhesion, sterilization, antibacterial adhesion combine with sterilization and antibacterial adhesion switch to sterilization [6,7]. Although bacteria-resistant surfaces largely prevent bacteria from initially attaching, they do not actively interact with or kill bacteria. Besides, it is difficult to find the same medical materials to replace the existing materials. Therefore, surface modification of materials is an effective strategy to reduce the risk of material adhesion to bacteria.

The surface immobilization method mainly fixes some physiologically functional biomolecules (such as proteins, peptides, enzymes and cells). The long factor on the surface of the material to be modified to serve as a ligand or receptor for adjacent cells and substrates, so that the surface forms a transition layer compatible with the living organism. This method does not affect the performance of the material, can maintain the activity of the biomolecule immobilized on the surface of the material, and can selectively design the surface of modified region of the material. Methods for immobilizing biomacromolecules on the surface of materials include physical adsorption, coupled grafting, photochemical grafting, and layer-by-layer self-assembly. The physical adsorption is an easy way to operate by soaking or spraying antimicrobials to the substrate surface through physical action and alternating self-assemble with biomolecules through multiple layers. Recently, polymer brush-based strategies have been developed and applied in a variety of fields [1-4]. For example, hydrophilic multi-walled carbon nanotubes (MWCNTs) incorporating water-soluble polymer brushes have been shown to effectively improve the mechanical strengths and water uptake of polymer hydrogels[5]. Polymer brush materials have high density of side-linking branches, various synthetic methods, sizes in the nanometer range, carriers have the effect of increasing the specific surface area and reactivity of the catalyst, and so on. In the past two decades, in organic nanotubes, stimulation-responsiveness Materials, biomedicine, solution self-assembly and organic or inorganic hybrid materials have been widely used in research fields. Among them, the positive surface graft polymer brush is widely used for surface modification of solid materials due to its excellent mechanical properties, chemical stability and surface functionalization modification. Therefore, engineering binary polymer brushes as surface coatings are likely to fulfill the needs of dual-functional surface coatings.

2. Preparation method of surface polymeric brush
The polymer chemical grafting method can make the modified materials attach to the substrate more firmly and not easy to fall off, which has become the focus of research in the field of preparing antibacterial surfaces. According to the different grafting methods of polymer on the surface, it is now divided into two methods: "grafting to" and "grafting from".

2.1. The "grafting to" method
"Grafting to" method is used to prepare polymers that contain active groups, which are fixed to the surface of materials by reaction with active sites on the surface of the substrate or by functional groups with good adhesion properties. Common covalent fixation methods include the introduction of polymers into the surface of a material through chemical bonds between PEG, polypeptide, polysaccharide, and other functional groups. Since the graft polymer is polymerized in advance in solution, the structure and molecular weight distribution of the polymer is more easily controlled and detected. However, the macromolecular polymer could not be completely diffused to the base surface for further grafting due
to the control of the brush grafting density. In order to improve the density of the brush grafting, dopamine, which has strong adhesion to both the substrate and the polymer, was modified to the end of the graft polymer and grafted.

The polymer having a functional end group can be synthesized by the above novel polymerization method, and the obtained polymer has a narrow molecular weight distribution, and the length of the polymer brush can be kept uniform. The surface of the substrate can be introduced by a coupling agent or a self-assembled monolayer (SAMs) to facilitate the synthesis of the polymer brush. Koutsos et al.[8,9] first synthesized a series of monodisperse (< 1.2) terminal thiol-based polystyrene by anionic polymerization, and then exposed the gold matrix to the polymer toluene solution. In the middle, a polystyrene brush connected by a chemical bond is formed on the gold surface. They used atomic force microscopy (AFM) to study the polymer conformation of these polystyrene brushes in poor solvents (water). Yang et al. [10] first prepared polymethylhydrogensiloxane and its derivatives, and formed ethylene-terminated SAMs on the surface of the silicon wafer, and then passed the polymethylhydroxane to the surface of the silicon wafer. Vinyl addition is grafted onto the surface of the wafer to form a polymer brush. Usually only a small number of polymers can be fixed to the surface of the substrate by a "graft to surface" method, and the degree of grafting of the polymer brushes synthesized by this method is low. To solve this problem, the researchers used a new "grafting from surface" technique to synthesize polymer brushes, which effectively produced covalently bonded, high graft density polymer brushes.

2.2. The "grafting from" method
"Grafting from" means that the initiator is first bonded to the surface of the substrate, and then the monomer is initiated to undergo in-situ polymerization to prepare a polymer brush. The combination of initiators on the surface of the substrate can be treated by a glow discharge in the presence of a plasma or a gas, or a self-assembled monolayer (SAMs) containing an initiator can be formed on the substrate.

(1) Synthesis of a polymer brush by a plasma or glow discharge treated substrate: The initiator can be easily and conveniently bonded to the surface of the substrate by plasma or glow discharge [11-14]. Ito et al. [11] used a high-frequency amplitude modulator to perform a glow discharge treatment on a PTFE permeable membrane in the presence of ammonia (pressure 66.6 Pa), which binds the amino group to the surface, followed by an amino group on the surface to initiate L-glutamic acid. The γ-benzyl ester N-carboxy anhydride is polymerized on a PTFE film to form a polymer brush, and then poly (L-glutamine γ-benzyl ester) is hydrolyzed to obtain a polyglutamic acid brush. This modified film can be used as a pH sensitive chemical valve. Using the same technique, they grafted poly(methacrylic acid) (PMAA) onto the surface of a polycarbonate (PC) permeable membrane [12,14], and poly[3-carbamoyl-1-(p-vinyl benzyl) (pyridinium chloride) (PCBVP) was grafted onto a PTFE membrane[13]. The PMAA brush modified film can also be used as a pH sensitive chemical valve, while the PCBVP brush modified film can be used as a redox sensitive chemical valve to control water penetration.

Park et al. [15] used an octadecyl(dimethyl-N,N-diethylamino)silane porous glass filter membrane for glow discharge treatment in the presence of air to bind the peroxide groups to the surface. A polymer brush was then prepared by heating the substrate in a solution of helical pyran-substituted MMA and MMA in dimethylformamide (DMF) at 60 °C for 4 h. The polymer brush modified glass filter membrane can be used as a light control valve, the principle is that the suspended spiral pyran is isomerized under the irradiation of ultraviolet rays, resulting in different solubility of the linked copolymer in toluene, thereby The membrane permeability can be controlled by ultraviolet light irradiation.

There are some disadvantages to using this technique to prepare polymer brushes. It is difficult to control the type and amount of initiator first, and the mechanism of surface polymerization has not been fully understood. Compared to plasma and glow discharge methods, the mechanism of surface polymerization is much more clearly defined by the use of SAMs technology to bond the initiator to the surface of the substrate.

(2) Synthesis of a polymer brush by conventional radical polymerization: In many reports, a polymer brush is prepared by a radical polymerization mechanism. First, the free radical initiator molecule is bound to the surface of the substrate, which usually involves several steps, that is, the anchor molecule
layer is first fixed on the surface of the solid substrate, and then the initiator is connected to the anchor molecule layer in one or more steps. Finally, the initiator is decomposed to initiate free radical polymerization to form a polymer brush. Boven et al. [16] first treated glass beads with 3-aminopropyltriethoxysilane (γ-APS), introduced an amino group on the surface, and changed it by an azo initiator containing acyl chloride end groups and γ-APS. The amide bond formed between the surface of the surface introduces the azo initiator to the surface (Figure 1.), and then initiates polymerization of the monomer on the surface to produce a PMMA brush.

![Figure 1. Schematic description of the concept for the preparation of ploymer brushes by grafting from](image)

Minkoetal.[17]first treated the surface of the silicon wafer with 3-glycidoxypropyltrimethoxysilane and reacted with 4,4’-azo (4-cyanovaleric acid) to form on the surface of the silicon wafer. The azo initiator monolayer is then allowed to polymerize the vinyl monomer to produce a polymer brush. Although these studies have successfully produced polymer brushes, there are still some disadvantages. Fixing the initiator to the surface first involves several steps, and the reaction may be incomplete, which reduces the grafting density of the initiator and polymer brush. Secondly, there may be side reactions in the reaction in which the initiator is immobilized on the surface, which will introduce an unexpected structure on the surface.

(3) Synthesis of polymer brushes by controlled radical polymerization: In order to control the molecular weight and distribution of the polymers better, synthetic polymer brushes, such as block polymer brushes, etc., have been used for controlled radical polymerization. Methods, including ATRP, reverse ATRP, and activated radical polymerization, etc., to prepare polymer brushes for solid surfaces [18, 19].

ATRP is a newly developed controlled radical polymerization method, which has attracted much attention because it can control the molecular weight and its distribution, and can synthesize block copolymers. Ejaz and Hussman et al. used the ATRP method to synthesize polymer brushes on the surface of silicon wafers with significant success. Ejaz et al.[18] used the Langmuir and Blodgett techniques to bind the ATRP initiator 2-(4-chlorosulfonylphenyl) ethyltrimethoxysilane to the surface of the silicate matrix and initiate MMA polymerization under appropriate conditions. A high graft density PMMA polymer brush was synthesized. Hussman et al.[19] prepared a self-assembled monolayer of 2-bromo-2-methylpropionic acid-5'-trichlorosilylpentyl ester on the surface of silicate, and then passed through the α-bromo ester. SAMs initiated the polymerization of MMA and successfully synthesized the PMMA brushes. It has also been reported that ATRP of acrylamide is initiated on the surface of a porous silicon wafer to synthesize a polyacrylamide brush [20].

3. Antibacterial surface construction strategy

In order to impart antibacterial properties to the surface of the material, it is necessary to carry out targeted antibacterial surface construction according to the mechanism of bacterial infection. The
strategy is mainly antibacterial adhesion strategy, sterilization strategy, and anti-adhesion bactericidal combination strategy [2,6,7].

3.1. Antibacterial adhesion strategy

Bacterial adhesion is the first step in the infection of biomedical materials and devices. Regulating the adhesion behavior of bacteria on the surface of materials is an important part of the preparation of highly effective antibacterial surfaces. Although the bacterial adhesion behavior is related to the type and biochemical properties of the bacteria, it mainly depends on the surface properties of the material/device, such as the chemical composition of the biomaterial/device surface, critical surface tension, interfacial energy, surface hydrophobicity, surface charge. Etc. has an effect on bacterial adhesion and biofilm formation[21]. The following is a detailed description of the antibacterial adhesion of materials and instruments to hydrophilic surfaces, superhydrophobic surfaces, and slip surfaces.

3.1.1. Hydrophilic surface. This surface is usually modified by a hydrophilic substance to form a hydration layer in an aqueous environment and inhibit the adhesion of bacteria on the surface of the material to avoid the occurrence of subsequent infection, which is one of the effective strategies for constructing an antibacterial surface[22]. Common hydrophilic modifying substances are polyethylene glycol[23-25], internal salts [25-26] and the like. Among them, polyethylene glycol utilizes the steric repulsion of hydration layer and molecular chain formed by the combination of hydrogen bonds and water molecules to inhibit anti-bacterial adhesion; the inner salt material uses the charge valence to bind water molecules to form hydration layer, inhibiting bacteria adhesion.

Smith et al.[28] grafted sulfonic acid inner salt on the surface of peripheral venous catheter by oxidation-reduction polymerization. In order to form a conformal polymer surface, Polymer Sulfobetaine(SB) is bound to the surface of PICC and this modification concert both free and bound water molecules to create a hydrophilic surface. The results show that the sulfonate internal salt modified catheter can effectively reduce a variety of bacteria on the surface of the material. Adhesion, while having excellent anticoagulant properties. The antibacterial mechanism is due to the hydration of the hydrophilic inner salt polymer through the ionic bond and the water molecule to form a dense hydration layer. The hydration layer inhibits adhesion of proteins, bacteria, human cells, and the like on the surface of peripheral venous catheters and biofilm formation.

Park et al.[29] used different molecular weight polyethylene glycols to modify the surface of medical polyurethanes, and studied the adhesion behavior of different bacteria (S. epidermidis and Escherichia coli) and proteins on the surface, and found that after surface modification The polyurethane surface, especially the high molecular weight polyethylene glycol, can significantly reduce the amount of bacterial adhesion.

3.1.2. Superhydrophobic surface. Hydrophobic interactions tend to cause bacterial adhesion to the surface of the material, which removes interfacial water and reduces system free energy by enhancing the interaction of bacteria with the surface[30,31]. However, superhydrophobic surfaces have excellent antibacterial adhesion properties. Hu et al.[32] used electrospray technology to prepare a superhydrophobic coating with micro-nano structure on the surface of titanium. The coating was prepared from degradable poly-L-lactic acid (PLLA)/modified silicon nanoparticles, compared with flat membrane. The bacteria adhered to the surface of the superhydrophobic coating by 75%. Privett et al.[33] prepared a fluorinated nano-silicon coating, and found that the surface of the coating has superhydrophobic properties, and the amount of adhesion of Staphylococcus aureus and Pseudomonas aeruginosa on the modified surface decreased by 2.08 and 1.75, respectively. There are three kinds of condition compared with the MTMOS blank:At the first, blank30 mol % 17FTMS xerogels which indicated that the adhesion of bacteria cannot be reduced only by lower the energy of the fluorinated surface; Then, for silica-colloid-coated substrates which are lack of the additional fluoroisilane film modification, those two were reduced to 0.93 log and 1.01 logs; At last, the adhesion of S. aureus and P. aeruginosa to the silica-colloid-doped fluorinated substrates was reduced to 2.08 logs and 1.76 logs.
3.1.3. Slip surface. Yin Jinghua's group [34] used UV grafting technology to prepare a polymer surface with a pleated structure and a fluoride polymer graft. This surface takes on a coarse morphology made of the combination of photo grafting polymerization and osmotically driven wrinkling, then infusing the fluorocarbon liquid so that it effectively "captures" the fluoro oil to form a complete, smooth fluoro oil film that imparts excellent anticoagulant and antibacterial properties to the surface. The amount of surface fibrinogen adsorption decreased by about 96%, almost no platelet adhesion, and the coagulation index increased to about 95%, indicating that the surface can effectively inhibit protein adsorption, platelet adhesion and coagulation, and has excellent blood phase. The adhesion of E. coli and S. aureus on this surface was reduced by about 98.8% and 96.9%, respectively, and showed excellent antibacterial adhesion properties.

Leslie et al. [35] prepared a slip surface that effectively inhibited the adhesion of blood cells and bacteria. The surface of the coating is chemically bonded to the flexible fluorocarbon chain to interact with the perfluoroliquid to form a "slip" liquid film. The study found that this coating can effectively reduce the adhesion and activation of platelets, inhibit the adsorption of fibrinogen and inhibit the formation of biofilm. At the same time, under the action of flow dynamic blood, the coating can still maintain stability and the modified catheter can inhibit the occurrence of blood coagulation within 8 hours. Although the anti-bacterial adhesion strategy can effectively reduce the adhesion of bacteria on the surface of materials or instruments and biofilm formation, it is impossible to achieve 100% inhibition of bacteria. Once a small number of bacteria adhere to the surface of materials or instruments, the anti-bacterial adhesion system is very difficult to stop the proliferation of bacteria.

3.2. Sterilization strategy
According to the sterilization mechanism, it can be divided into release type and contact type sterilization. Contact type sterilization is carried out by constructing cationic polymer, antibacterial peptide, active oxygen, carbon nanotubes [36], etc. on the surface of the material, and directly acting on the bacteria through surface contact. The bactericide is released from the inside of the material to the environment to achieve bactericidal action. The bactericide includes antibiotics, silver ions/nanoparticles [37,38], and nitrogen oxides [39], etc., which could kill bacteria adhering to the surface of the material to achieve antibacterial effect.

3.2.1. The release type antibacterial surface. The release type antibacterial surface refers to the use of certain physical and chemical methods to add antibacterial materials to the existing material, or to prepare an antibacterial coating on its surface by surface modification technology. In use, the antibacterial agents released from the material or surface coating kill bacteria that adhere to the surface of the material and travel near the interface, thus preventing the formation of the biofilm. Polyacrylonitrile-vinylpyrrolidone copolymer was synthesized by water phase precipitation polymerization, then mixed with silver carrier molecular sieve and pore agent to dissolve two methyl sulfoxide and made spinning solution through filtration and defoaming [40]. The polyacrylonitrile hollow fiber membrane with antibacterial properties was obtained by spinning, washing and pore holding, and the resistance to S. aureus and E. coli was obtained. The rate of bacteria reached more than 87%.

Metal ions and their nanoparticles are one of the substances commonly used to prepare bactericidal surfaces, of which silver is a well-known bactericidal metal. The principle of sterilization is that silver can decompose in water to produce a small amount of anions, which can adsorb to the surface of bacteria and sterilize bacteria by destroying the activity of certain enzymes of bacteria. Ag⁺ has been introduced to the surface of the material by spraying, physical mixing, and electrostatic interaction, and has been proven to have good bactericidal ability. Ag⁺ is introduced into the PCBMA polymer brush by electrostatic action and can be slowly released into the environment [41]. Antimicrobial testing found that the composite Ag⁺ of PCBMA polymer-modified surface was able to kill more than 99.8% of E.coli adhering to the surface antibacterial experiment and was able to release more than 97.8% of the bacteria in one-hour.
Silver nanoparticles also have the bactericidal properties. Dai et al.[42] introduced a composite of silver nanoparticles and a polyelectrolyte multilayer film onto the surface. Cuong et al.[43] reduced silver ions into silver nanoparticles in acidic solution of chitosan and polyacrylic acid. The nanocomposite film were found to have lethality against both Gram-negative E. coli and Gram-positive Staphylococcus epidermidis. In recent years, copper has been found to have a certain antibacterial ability, and a similar method is used to fix copper particles or nano-copper on the surface of the material to achieve an antibacterial effect. However, the potential toxicity of metal ions, the uncontrollable releasing and releasing rate limit their use as surface materials for biomaterials.

Since the discovery of penicillin, antibiotics have been widely used in the medical field, which has greatly reduced the dyeing rate of postoperative feeling. But 40 years after the discovery of antibiotics, it was the first time that someone introduced antibiotics to the surface of biological materials[44]. The earliest preparation of method was to directly immerse the biological material in a solution containing antibiotics to obtain an antibacterial surface. Stigter et al.[45] complexed different antibiotic molecules into hydroxyapatite and introduced them onto the titanium surface by deposition. Different antibiotics have different compatibility with hydroxyapatite, and antibiotics containing carboxyl groups such as amoxicillin, cephalosporin, carbenicillin and cefmenoxime have good compatibility. And these antibiotic composite hydroxyapatite coatings have good antibacterial properties against Staphylococcus. Hammond et al.[46] complexed gentamicin into a layer-by-layer self-assembled polyelectrolyte multilayer film. It was found to be slowly released from the surface, which can release 95% of gentamicin for about 10-15 hours. Releasing rate is determined by factors such as the number of layers of polyelectrolyte.

Like the metal ions, the use of antibiotics in large quantities can cause bacterial resistance, so its application is limited. Antibacterial peptides are a class of alkaline polymers with antibacterial activity, which were first induced in insects. It has a broad-spectrum antibacterial activity that a small dose can have a strong killing effect on bacteria and the killing effect has attracted the interest of scientists on certain drug-resistant pathogens. It mainly acts on the bacterial cell membrane to produce an antibacterial effect, but the specific antibacterial mechanism has not yet been elucidated. Introducing antibacterial agents into the surface of materials has become a hot spot in recent years.

3.2.2. The contact type antibacterial surface. The antibacterial substances with suitable chemical structure are fixed onto the surface of the material by grafting, coupling or covalent binding, forming a contact bactericidal antibacterial surface. Unlike release-type antibacterial surface, antibacterial components of contact-type antibacterial surfaces tend to be fixed to the surface of the material for a long time and have a killing effect on bacteria adhering to the surface of the material. Once the bacteria touch the surface of the biological material, they will be inhibited or killed, so that they cannot grow and reproduce. So they can give the biomaterial a favorable environment for a long-term existence. At the same time, the contact-type antibacterial surface does not release the risk of potential damage to the human body by releasing the antibacterial substance around the material. Polymer antibacterial agents, especially polycation, such as quaternary ammonium salts, have higher positive charge density than small molecular quaternary ammonium salts, stronger interaction with bacteria, and thus exhibit more efficient antibacterial activity. Research on this area has attracted much attention[48]. For this reason, people began to try polycation in the last ten years, such as polycation. Pyridinium salts, polyquaternary ammonium salts and chitosan were fixed onto the surface of the materials and their antibacterial properties were studied[49]. Common bactericidal substances used to prepare contact surfaces are halogen bactericidal molecules, polymer bactericidal molecules, and photocatalytic bactericides.

Many halogen-containing molecules have bactericidal properties, and because of their strong oxidizing properties, halogen atoms can destroy bacterial bacterial membranes and thus have good bactericidal ability. Commonly known as triclosan, it is a broad-spectrum fungicide with good bactericidal properties against common bacteria. Triclosan is a safe fungicide, which is an additive in daily necessities such as toothpaste, body wash, and even in human body fluids such as liver, blood, and the like[47-50]. Therefore, it is considered to be a green, safe fungicide. Orhan et al.[51] introduced
The ammonium salt polymer is mainly fixed to the surface of the material by covalent bonding. Tiller et al.[52] studied and reported the bactericidal mechanism of quaternary ammonium salt polymers. The strong electrostatic interaction and hydrophobic interaction of quaternary ammonium salt polymers can destroy the cell membrane of bacteria and kill bacteria. Further, Tiller et al.[53] immobilized the poly-4-vinylpyridine to the surface of the glass by a covalent bond, and then treated the modified surface with an alkyl bromide to obtain a polycation-modified surface. They treated the surface of the poly-4-vinylpyridine polymer that modified with alkyl bromides of different carbon numbers and evaluated their bactericidal ability with Staphylococcus epidermidis, Staphylococcus aureus, Escherichia coli and Pseudomonas aeruginosa. It was found that when the number of alkyl bromide carbon atoms is more than 9, the resulting polycation-modified surface has little bactericidal ability compared to the poly-4-vinylpyridine-modified surface. The polycation-modified surface obtained after bromohexane treatment can kill more than 94% of bacteria. Therefore, they believe that the appropriate alkyl chain length is an important factor in the successful preparation of polycation-modified bactericidal surfaces with good bactericidal properties.

The sterilization principle of photocatalytic fungicide is that it can generate active oxygen under illumination conditions, thereby killing bacteria, and its photocatalytic sterilization mechanism is as shown. Common photocatalytic bactericidal substances are porphyrin, toluidine blue, methyl blue, rose red and some metal oxides such as TiO$_2$, ZnO and the like[54]. Bojaz et al.[55] grafted the porphyrin onto the nylon fiber, first fixing the PAA to the nylon fiber, and then grafting the porphyrin compound onto the PAA polymer. The porphyrin-modified nylon can have good bactericidal properties against staphylococci under indoor light conditions, and the sterilization efficiency is enhanced as the light intensity is enhanced. However, it does not have bactericidal ability for E. coli. This indicates that the porphyrin fungicide has good bactericidal properties against Gram-positive bacteria and has no killing performance against Gram-negative bacteria. Moudgil et al.[56] prepared TiO$_2$-coated carbon nanotubes, which sterilized Bacillus twice as much as commercial TiO$_2$.

3.3. The anti-adhesion bactericidal combination strategy

The surface of antibacterial adhesion is a function of preventing bacterial adhesion by surface modification, but a small amount of adherent bacteria may become dangerous through continuous proliferation with time. A simple bactericidal surface prevents infection by killing adhering bacteria. However, as the dead bacteria continue to accumulate, their bactericidal ability will continue to weaken. Therefore, both of these modified surfaces are only suitable for short-term antibacterial.

In order to obtain a surface with longer-lasting bactericidal properties, many researchers have now used both methods on one surface to prepare a surface having both antibacterial adhesion and bactericidal ability. This not only improves the antibacterial efficiency of the modified surface, but also maintains the surface antibacterial properties for a longer period of time. As mentioned above, the most important surface for antibacterial adhesion is to modify the surface with a polymer, while the bactericidal surface is a bactericidal substance.

Bioactive bactericidal molecules such as bactericidal peptides are widely used in the preparation of anti-adhesive-sterilization composite surfaces. Bactericidal peptide is a bactericidal molecule that is of great concern at present. It has the following advantages: it has good broad-spectrum bactericidal performance; it does not improve bacterial resistance compared with traditional fungicides; Bactericidal polypeptides are generally composed of less than 50 amino acids, most of which are positively charged, killing bacteria by destroying the cell membrane of the bacteria. Glinel et al. first grafted the bactericidal polypeptide onto the polymer brush. They first copolymerized 2-(2-methoxyethoxy)ethyl methacrylate and hydroxy-terminated oligo(ethylene glycol) methyl methacrylate on the surface of the wafer and then brushed it through the polymer. The hydroxyl group reacts with the thiol group on the polypeptide, and the bactericidal polypeptide is grafted onto the polymer brush. They used several Gram-positive bacteria to perform antibacterial experiments on the surface of the modified silicon wafer and found that almost...
no bacteria adhered to the surface modified only by the polymer; while very few (about 1%) of the bacteria adhered to the silicon of the grafted peptide. The surface of the sheet, but all adhering bacteria were killed, demonstrating that the surface grafted with the polypeptide has bactericidal properties. Whether the bactericidal polypeptide is grafted into the polymer brush can effectively contact the adhered bacteria has attracted their attention.

The combination of antibacterial adhesion and sterilization methods can avoid the shortcomings of each of the two ways. The main methods used in this way are as follows: graft copolymerization of anti-sticky and bactericidal monomers, blends of anti stick brush and germicidal brush, and synergism of anti brush and release fungicides. Yang[57]synthesized the polycarbonate copolymer containing anti fouling (polyethylene glycol), bactericidal (cationic) and adhesive (dopamine) multifunctional components.(As shown in Figure 1). The copolymer can effectively kill Escherichia coli and Staphylococcus aureus in aqueous solution, and is effective when immobilized on the surface of the material. Inhibition of bacterial adhesion. When used as a coating, it still maintains excellent antifouling and bactericidal activity for 14 days in contact with Staphylococcus aureus, and also inhibits protein adsorption and platelet adhesion, and has excellent blood compatibility. The polymer can be coated on the surface of the catheter in one step. The medical catheter has the function of anti killing, and the antibacterial property is durable and stable.

Lysozyme is a bactericidal protein that is also immobilized on the surface of different polymer-modified materials for the preparation of anti-adhesive-sterilization composite surfaces. The polyethylene glycol (PEG) monomer is polymerized on the surface of the stainless steel to obtain a P(OEGMA) polymer brush on the surface; then the lysozyme in the chicken protein is fixed to P(OEGMA) by activating the hydroxyl group on the polymer chain. Molecular brush. It was found that the surface had bactericidal properties against Staphylococcus aureus and Escherichia coli after immobilized lysozyme. In addition, lysozyme is also introduced into the surface of the triblock polymer modified by PEO and PPO. The PEO-PPO-PEO polymer is fixed to the surface by hydrophobic interaction, and then the hydroxyl group on PEO is oxidized to aldehyde group, and then lysed. The amino group reaction on the enzyme covalently grafts the lysozyme to the polymer. They used Bacillus subtilis for antibacterial testing. After 20 hours of incubation in bacterial solution, the modified surface was found to be effective in reducing bacterial adhesion while killing 80% of the bacteria adhering to the surface. In addition, they also found that the surface with low lysozyme grafting density has better antibacterial adhesion and bactericidal activity than the surface with high graft density, which may be due to the low grafting density of lysozyme in the polymer brush. Have more freedom. In summary, grafting lysozyme onto a polymer brush can improve the bactericidal ability of the surface, but because it is a protein, it is easily inactivated by the environment and the conformational change after grafting. The application of lysozyme on the sterilizing surface needs further the study.

The bactericidal polymer is also used in combination with an anti-bacterial adhesion polymer brush to prepare a surface that has both antibacterial adhesion and bactericidal properties. Common bactericidal polymers are polycationic polymers such as quaternary ammonium polymers, natural chitosan and the like. Yao et al.introduced a copolymer of PEGMA and PDMAEMA onto the PP fiber membrane, and then quaternized the PDMAEMA end with dodecyl bromide to obtain a copolymer brush of PEGMA and PDMAEMA quaternary ammonium salt. It was confirmed by bacterial experiments that the modified surface of the copolymer was able to kill 99% of S. aureus and E. coli and maintained good antibacterial adhesion properties possessed by PEGMA. However, due to its toxicity and poor biocompatibility, the introduction of such cationic polymers to the surface of biological materials may cause damage to the body tissues, thereby greatly limiting its application. Chitosan, as a natural polysaccharide material, has good biocompatibility and bactericidal properties, and is also used to improve the bactericidal properties of the surface of the material. The modified stainless steel surface has good bactericidal properties, and the surface surviving bacteria is about 20%. At the same time, the total amount of the dead and live bacteria adhering to the modified surface is similar to that of the PHEMA modified surface, indicating that the modified surface of the chitosan maintains the good antibacterial adhesion properties of the PHEMA polymer brush. Chitosan has received more and more
attention due to its good biocompatibility, but its relatively mild bactericidal performance and its vulnerability to environmental pH have also limited its application to some extent.

According to the sterilization mechanism, it can be divided into contacting type and releasing type sterilization. The sterilization of contacting type can form a cationic polymer antibacterial peptide[58,59], active oxygen[60], carbon nanotubes[61], and directly act on the bacteria on the surface of the material; The sterilization of releasing type can be sterilized by the release of the bactericide from the inside of the material to the environment, and the bactericide Including antibiotics, silver ions/nanoparticles, nitrogen oxides, can kill bacteria adhering to the surface of the material to achieve antibacterial effect[62-65].

4. Summary and perspective
Over the past years, a significant number of dual-function antibacterial surfaces have been developed for the prevention of initial bacterial attachment and biofilm formation. Although considerable progress has been made in this area, many challenges in both science and technology remain. The main challenge of assembling binary polymer brushes on substrates surface is the difficulty to functionalize two different types of polymer chains with high grafting density while maintaining the polymer brush structure. The problem of microbial contamination is the hotspot and difficulty in the application of membrane separation technology. Therefore, it is great practical significance to develop high effective antibacterial materials and antibacterial surfaces with good stain resistance. However, the currently developed antibacterial surface is still in the early stages of the experiment and is not mature enough. The universal problems mainly include: shorter antibacterial period, lower antibacterial efficiency, and environmental pollution et al. Facing these difficulties and challenges, we need to develop new long-lasting, more efficient, and environmentally friendly antibacterial composite surfaces based on our original achievements.

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