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医用不锈钢高效抗菌表面飞秒激光加工研究

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摘要：全球每年因医源性感染导致的死亡人数过百万，而具有抗菌性能的医疗器械被证明可有效减少外科手术治疗过程中的医源性感染。研究发现具备表面自清洁特性的表面可以有效阻止细菌的定植和成膜，降低器械表面细菌污染的风险。当前自清洁表面抗菌主要通过超疏水特性来减少菌液在表面的停留来实现，但研究表明具备最佳抗细菌粘附的亚微米结构与构建超疏水自清洁表面所用微米级结构并不完全重合，因此超疏水表面仍然可能导致细菌的残留定植。基于此，本研究基于飞秒激光加工技术在医用不锈钢表面构建了不同结构及形貌的超疏水表面，使用表面能改性剂对加工表面进行表面改性加工，通过扫描电镜、X 射线光电子能谱及接触角测量仪表征了超疏水表面微观形貌、化学成分及水接触特性。经过细菌培养及染色实验研究了不同超疏水表面抗细菌粘附及成膜的特性。研究表明医用不锈钢超疏水表面不一定超抗菌，接触角在 170° 左右，结构间距为 110μm 的医用不锈钢超疏水表面具有最佳的抗细菌粘附及成膜性能，其抗细菌粘附/成膜性能较抛光表面提升了 80%以上。而结构间距为 200μm 以上的医用不锈钢表面则抗细菌粘附效果不佳。本研究为不锈钢医疗器械高效抗菌表面的制造提供了参考。

关键词：不锈钢；超疏水表面；飞秒激光；抗菌表面

Abstract: More than a million deaths from iatrogenic infections occur globally every year, and antibacterial medical devices have proven effective in reducing iatrogenic infections during surgical treatment. It was found that surfaces with self-cleaning characteristics could effectively prevent bacterial colonization and film formation and reduce the risk of bacterial contamination on the surfaces of instruments. Currently, the antibacterial effect of the self-cleaning surface is mainly achieved by reducing the retention of bacterial liquid on the surface through superhydrophobic properties. However, studies have shown that the submicron structure with the best antibacterial adhesion does not completely coincide with the micron structure used to construct a superhydrophobic self-cleaning surface. The superhydrophobic surface may still lead to the residual colonization of bacteria. Therefore, we constructed superhydrophobic surfaces with different structures on the surface of medical stainless steel using the femtosecond laser. The surface microstructures, chemical composition, and water contact characteristics of the superhydrophobic surface were characterized by scanning electron microscopy, X-ray photoelectron spectroscopy, and contact angle measurement, respectively. The characteristics of bacterial adhesion and bio-film formation on different superhydrophobic surfaces were studied by bacterial culture and staining experiments. Studies have shown that the superhydrophobic surface of medical stainless steel is not necessarily super-antibacterial. Surfaces with a contact angle of around 170° and a structural spacing of 110μm have the best resistance to bacterial adhesion and biofilm formation, with antibacterial/antibiofilm performance improvements of over 80% compared to polished surfaces. Conversely, surfaces with a structural spacing of 200μm or more have shown poor resistance to bacterial adhesion. These findings provide valuable insights for the development of highly effective antibacterial surfaces for stainless steel medical devices.

Keywords: Stainless Steel; Superhydrophobic Surface; Femtosecond Laser; Antibacterial Surface

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