医用钛合金飞秒激光刻蚀表面免疫调控特性研究

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摘要：外科植入体易导致人体产生免疫反应，进而影响术后恢复时间，严重时甚至导致死亡。调控免疫反应的关键在于调控植入体周边巨噬细胞的表型表达。巨噬细胞的抗炎表型表达可抑制人体免疫反应，促进组织愈合。研究证实，材料表面微结构可调控巨噬细胞的表型，有效缓解免疫反应。基于此，本研究提出在医用钛合金表面构建了微米-纳米跨尺度多维微结构，通过医用钛合金表面微米-纳米多维度微结构实现巨噬细胞行为的调控，进而促进其抗炎表型的表达。研究基于飞秒激光刻蚀技术，结合化学腐蚀加工，在医用钛合金表面成功构建了 4 种多维度微纳结构。通过扫描电镜、X 射线光电子能谱和接触角测量仪表征了激光-化学复合加工表面物理及化学特性。并通过免疫细胞培养、细胞形态和分泌因子浓度检测，对不同密度微结构表面免疫调控特性进行了表征，获得了具备高效诱导抗炎表型的医用钛合金表面微结构。研究结果表明，在医用钛合金表面 10 line/㎜和 20 line/㎜密度微米结构下，通过 20 分钟氢氟酸刻蚀处理的表面可使得免疫细胞抗炎因子分泌浓度相对原始抛光面有显著提升，并且维持了原有的生物相容性，有效调节材料在修复过程中的免疫反应。本研究为钛合金植入体免疫调控表面制造提供了理论支撑和参考。

关键词：医用钛合金；飞秒激光；免疫调控

Abstract： Surgical implants can lead to an immune response in the human body, which in turn affects the recovery time after surgery. The key to regulating the immune response lies in regulating the phenotypic expression of macrophages around the implant. The anti-inflammatory phenotype expression of macrophages suppresses the human immune response and promotes tissue healing. Studies confirmed that the microstructure on the surface of the material can regulate the phenotype of macrophages and effectively alleviate the immune response. Therefore, we constructed a micro-nano cross-scale multi-dimensional microstructure on the surface of medical titanium alloy for leading the anti-inflammatory phenotype of macrophages using femtosecond laser-chemical etching technology. Four kinds of multi-dimensional micro-nano structures were successfully constructed on the surface of medical titanium alloy. The physical and chemical properties of the laser-chemical composite machining surfaces were characterized by scanning electron microscopy, X-ray photoelectron spectroscopy and contact angle measurement respectively. The immunoregulatory properties of the surface of microstructures with different densities were characterized, and the surface microstructures of medical titanium alloys with highly induced anti-inflammatory phenotypes were obtained. The results show that under the 10 line/mm and 20 line/mm density microstructure on the surface of medical titanium alloy, the surface treated by hydrofluoric acid etching for 20 minutes can significantly increase the secretion concentration of anti-inflammatory factors of immune cells compared with the original polished surface.Meanwhile, the original biocompatibility was maintained. This study provides theoretical support and reference for the fabrication of immunomodulatory surfaces for titanium alloy implants.

Key word： Medical titanium alloy; Femtosecond laser; Immunoregulatory

参考文献：

[1] Zhang Yue; Robles-Linares Jose A.; Chen Lei; Liao Zhirong; Shih Albert J.;Wang Chengyong;Advances in machining of hard tissues – From material removal mechanisms to tooling solutions,*Int J Mach Tool Manu*, **2021, 172(3)**: 103838.

[2] Chen Zhihua, Zhang Yue, Wang Chengyong, Chen Bin , Understanding the cutting mechanisms of composite structured soft tissues, *Int J Mach Tool Manu*, **2020**,**161**,103685.

[3] Du Cezhi, Yang Yuhe, Zheng Lijuan, Zhang Tao, Zhao Xin, Wang Chengyong, Structure-Element Surface Modification Strategy Enhances the Antibacterial Performance of Zr-BMGs, *ACS Appl Mater Inter*, **2022**,**14(7)**,8793-8803.

[4] 王成勇；陈志桦；陈华伟；宋清华；任莹晖；隋建波；舒利明；陈滨；郑李娟 ；生物骨材料切除理论研究综述，机械工程学报，2021, 57(11): 2-32.

[5] Cezhi Du,Chengyong Wang*,Tao Zhang, Lijuan Zheng, Antibacterial Performance of Zr-BMG, Stainless Steel, and Titanium Alloy with Laser-Induced Periodic Surface Structures,*ACS Applied Bio Materials*,**2022,5,1,**272-284.

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