Abstract

Cell adhesion plays a critical role in regulating cellular survival, proliferation, migration, and tissue regeneration, making it a key factor in the performance of biomedical implants and tissue-engineered scaffolds. However, inadequate interactions at the cell–material interface often led to fibrosis, scarring, insufficient tissue integration, or implant failure. Therefore, understanding how material surface properties influence cellular behavior is essential for the development of advanced biomaterials for regenerative medicine and tissue engineering applications. This thesis investigates the modulation of cell adhesion through electroactive, chemical, and topographical cues by tailoring the properties of biomaterial surfaces. Different surface engineering strategies have been explored to examine how parameters such as surface charge, wettability, roughness, topography, electrochemical properties, and bioactive chemistry affect cell–material interactions. Nanoscale topographical engineering of titanium surfaces revealed that nanoarchitectures strongly influence cellular morphology, adhesion, migration, and network formation. Chemical functionalization of the titanium surface using bioactive polymer coatings enabled selective modulation of cellular adhesion while simultaneously promoting bioactivity and mineralization. Conducting polymer coatings improved electrochemical performance by increasing electroactive surface area, reducing impedance, and enhancing charge transfer at the electrode–tissue interface, while also supporting neural cell adhesion and neurite outgrowth. Electroactive modifications of electrospun polymeric scaffolds demonstrated that altering surface charge and conductivity significantly improved cellular attachment, and cell spreading. Overall, this work demonstrates that cellular responses can be effectively directed through precise control of surface properties. By integrating electroactive materials, chemical modifications, and nanoscale topographical features, this thesis contributes to the development of multifunctional biomaterial interfaces with improved performance for biomedical implants, neural interfaces, and tissue scaffolds.