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Abstract

Automated Analysis of Cell Motility on Structured Surfaces

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The long-term performance of orthopedic and dental implants remains a major clinical challenge, largely due to insufficient osseointegration at the bone–implant interface [1]. Early interactions between osteoblast cells and implant surfaces, including cell adhesion, spreading, and migration, are critical determinants of implant stability [2]. Time-lapse microscopy is the state-of-the-art method for continuous observation of these dynamic cell processes [3]. To enable quantitative analysis of such data, cells must be reliably segmented and tracked over time [4]. However, the increasing volume of image data renders manual segmentation and tracking error-prone and non-scalable. This challenge is further amplified on structured biomaterial surfaces, as cells move in three dimensions, change morphology along edges or pores, and span multiple height levels, leading to partial and transient loss of focus.

In this work, we present an automated workflow for time-resolved quantitative analysis of cell motility on structured biomaterial surfaces. The approach integrates deep learning–based cell segmentation with automated tracking to analyze fluorescence time-lapse microscopy data of osteoblasts cultured on titanium surfaces with varying topographies. The pipeline reconstructs cell trajectories and extracts key features, including migration speed, directionality, cell morphology, and alignment relative to surface structures. The performance was evaluated against manual annotations reviewed by cell biologists, using quantitative metrics and visual validation.

Overall, this work demonstrates that automated segmentation and tracking can enable robust analysis of osteoblast motility on structured biomaterial surfaces, significantly reducing manual effort while increasing reproducibility. This allows, for the first time, a systematic time-resolved quantification of cell migration, morphology, and alignment on structured surface topographies, thereby expanding both the scope and depth of cell–material interaction studies.

Author's Statement

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