

Title

Innovations in biomedical optical imaging for translational medicine: from in-vitro organoid analysis to vascular mapping in dermatology

Abstract

Biomedical optical imaging encompasses a range of non-invasive techniques that exploit light-tissue interactions to provide high-resolution structural and functional information, enabling advances in both fundamental research and clinical care. Despite the rapid evolution of optical technologies, several open challenges remain, including the lack of standardization in image processing pipelines, limitations in new system regulatory compliance, the many promising applications that are still unexplored, and the need for robust, interpretable tools that bridge the gap between laboratory innovation and clinical implementation. The studies presented in this thesis aim to address these gaps by proposing comprehensive, scalable solutions that advance the field toward safer, more effective, and more accessible optical imaging platforms across pre-clinical and clinical settings.

The first experimental section investigates the potential of optical imaging in a pre-clinical setting, at the microscale level. Optical Coherence Microscopy (OCM) and Photoacoustic Microscopy (PAM) are examined within the European project REAP for the detection of drug-tolerant persister cells. A complete OC-PAM acquisition and processing pipeline was developed to be integrated into a custom triple-modality software platform within REAP. The pipeline was linked with 3D Slicer modules to enable comprehensive image visualization and analysis. The workflow was evaluated and discussed for its potential impact on cancer treatment and organoid evaluation.

The second part of the thesis focuses on the evolution of optical imaging in a clinical setting. Specifically, Optical Coherence Tomography Angiography (OCTA) in dermatology was explored. Several clinical case studies are presented, including the analysis of vascular networks in chronic venous diseases, the staging of actinic keratosis, and the monitoring of radiotherapy response in non-melanoma skin cancer. For each application, specific data acquisition strategies, image analysis pipelines, and quantitative outcomes are reported. A key contribution is the development of AI-based OCTA segmentation tools, supported by the release of the open-access *DERMA-OCTA* dataset. Both 2D and 3D segmentation approaches are compared using accurate evaluation metrics. The work also includes a comprehensive assessment of Medical Device Regulation (MDR) compliance for the high-resolution OCTA system used for the reported studies, covering electrical, optical, and mechanical safety aspects.

In conclusion, this thesis offers a multidisciplinary framework that strengthens optical imaging workflows, with specific advancements in OCM and PAM for cellular-level pre-clinical organoid evaluation and in OCTA for non-invasive vascular assessment in clinical dermatology. These contributions combine technical innovation and clinically relevant insights to support the integration of biomedical optical imaging into translational medicine.