Advanced Imaging Techniques for Biomedical Applications

M. Fratini

CNR- Nanotec, c/o Dip. Fisica, Sapienza Univeristà di Roma, Roma 00185

IRCCS Fondazione Santa Lucia Rome Italy

michela.fratini@gmail.com

Abnormalities or damage within the vascular and neuronal networks of the central nervous system are implicated in a wide range of severe pathologies. To detect subtle anomalies at the level of the smallest capillaries and neuronal structures, high-resolution imaging of both vasculature and cytoarchitecture is essential. However, conventional MRI lacks the spatial resolution required to visualize microvascular and neuronal organization below the voxel scale. Addressing this limitation is critical for unraveling the intricate neurovascular interactions that underlie healthy and diseased states.

X-ray Synchrotron Phase-Contrast Tomography (XPCT) has emerged as a transformative imaging modality, capable of revealing soft tissue structures with low absorption contrast and generating detailed 3D image stacks for comprehensive analysis [1, 2]. In this study, we employed XPCT to achieve high-resolution visualization of both microvascular and macrovascular networks, as well as cytoarchitecture, in the mouse brain and spinal cord. This approach enabled robust qualitative and quantitative assessments of tissue morphology.

To further enrich our analysis, we adopted a multimodal imaging strategy (figure 1), integrating XPCT with MRI, X-ray microdiffraction, fluorescence imaging, and histological techniques [3]. This holistic framework allows for a multiscale evaluation of tissue damage, offering unprecedented insights into pathological mechanisms and facilitating the identification of novel biomarkers. Notably, we developed a novel adaptive algorithm to co-register high-resolution XPCT datasets with MRI scans from the same specimens, producing easily interpretable 3D reconstructions that highlight diverse tissue types.

By synergizing XPCT, Xray microdiffraction, and MRI, we not only deepen our understanding of MRI contrast mechanisms—a cornerstone of non-invasive clinical diagnostics—but also unlock the potential for comprehensive 3D mapping of neurovascular structures. This advancement provides a powerful foundation for studying the impacts of spinal cord injury and neurological disorders, and it represents a major step toward the development of next-generation biomarkers for biomedical research and clinical applications.

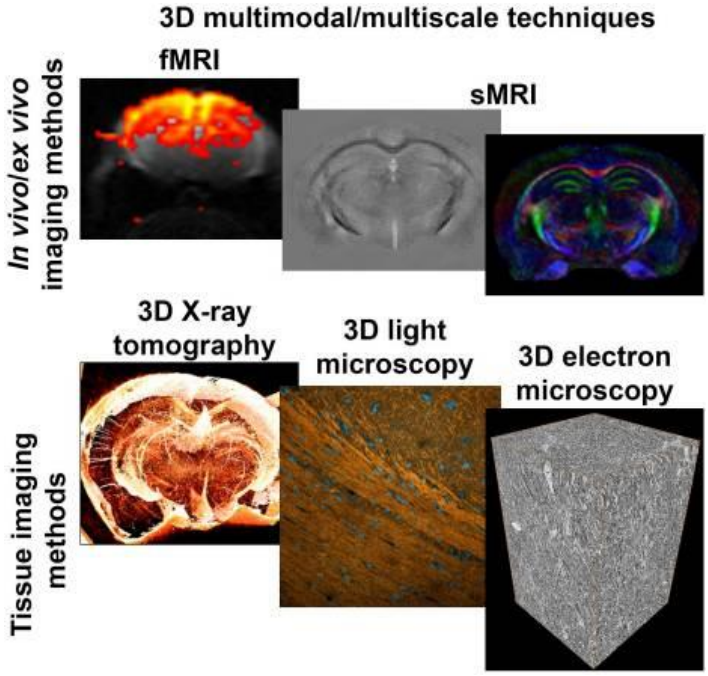

Figure 1: pictorial view of an example of 3D multimodal approach

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