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PhD THESIS DEFENSE | Hybrid diffuse optical monitoring and imaging: New approaches and applications in muscle and brain

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December 05, 2025
10:00
ICFO Auditorium

The generation of energy in the human body relies on oxygen metabolism, determined by oxygen delivery through blood flow and extraction at the tissue level. Reliable assessment of these parameters is crucial for understanding physiological function and tissue adaptations under various stimuli. Conventional monitoring tools for blood flow and oxygen saturation face trade-offs between cost, portability, and technical limitations (depth, resolution, dynamics), restricting their real-time deep-tissue use.
This thesis advances diffuse optics, a non-invasive, safe, scalable approach exploiting light diffusion in scattering media, and introduces methodological and instrumental innovations

for monitoring blood flow and oxygenation in adult skeletal muscle and brain-two of the most oxygen-demanding organs.

Part I investigated long-term physiological adaptations in forearm muscles of advanced rock climbers versus healthy controls. Rock climbing requires exceptional grip endurance, making it an ideal model for localized neuromuscular and hemodynamic adaptations to chronic training. Two protocols were applied: (1) a resting vascular occlusion test (VOT) combining near-infrared spectroscopy (NIRS, oxygenation) and diffuse correlation spectroscopy (DCS, blood flow), and (2) an intermittent grip endurance test measuring force, NIRS, and electromyography (EMG). Results showed climbers had faster blood flow recovery and higher hemoglobin concentrations after occlusion, indicating enhanced vascular response. During exercise, they maintained force longer and used oxygen more efficiently. However, steady-state measures revealed no significant inter-group differences, suggesting adaptations are demand-driven rather than evident at rest. This study is novel in (1) applying DCS to climbing physiology and (2) integrating mechanical, neuromuscular, and hemodynamic measures in one framework.

Part II focused on high-density (HD) cerebral blood flow (CBF) mapping, a key marker of brain metabolism. Current systems are bulky, costly, and clinical-only. We developed a new diffuse optics platform using speckle contrast optical spectroscopy (SCOS) and its tomographic extension (SCOT), leveraging cost-effective CMOS technology to improve signal-to-noise ratio (SNR) and scalability while retaining cortical sensitivity. A fiber-based prototype validated signal quality and flow sensitivity in forearm and forehead tests. Building on this, we designed a full-scale HD-SCOT system, nearing completion, intended for real-time, non-invasive mapping of CBF over large cortical areas (e.g., visual cortex).

Final contribution: a proof-of-concept SCOS extension enabling simultaneous blood flow and oxygenation measurement. Using multiple wavelengths, source-detector separations, and exposure times, it offers a simplified alternative to dual NIRS-DCS systems. Preliminary forearm tests confirmed feasibility, suggesting applications in muscle and brain monitoring.

In summary, this thesis advances diffuse optical monitoring by developing new instruments and methodologies for deep-tissue hemodynamics. Applications in sport physiology and neuroimaging highlight the potential of multi-modal, high-density optical systems to deepen understanding of oxygen metabolism in naturalistic, real-time contexts, paving the way for broader physiological and clinical applications.

Friday December 5, 10:00 h. ICFO Auditorium

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