AI: The Missing Link for Translational Biophotonics

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Abstract— Over the past decades, biophotonics has produced a wide range of powerful technologies capable of probing biological systems with unprecedented molecular specificity. Among them, Raman spectroscopy, fluorescence imaging, and nonlinear optical microscopy provide detailed biochemical and structural information across multiple spatial and temporal scales. Yet despite remarkable technological progress, only a limited number of these approaches have achieved broad clinical adoption.

This lecture argues that artificial intelligence (AI) is the missing link required to translate photonic innovation into clinical impact.

Modern photonic technologies generate highly complex, high-dimensional datasets that often exceed the interpretability of conventional analytical approaches. AI transforms these molecular and functional fingerprints into clinically actionable information, enabling objective diagnostics, predictive analytics, and real-time decision support.

Examples from infection diagnostics and precision oncology will demonstrate how AI-driven Raman spectroscopy and multimodal imaging can support rapid pathogen identification, assessment of host responses, tissue characterization, and intraoperative guidance. Beyond these applications, the lecture will also provide an outlook on the emerging concept of optical digital twins, where photonic, clinical, and physiological data are integrated into dynamic patient-specific models for predictive diagnostics, therapy monitoring, and personalized medicine.

Together, these examples illustrate that the future success of translational biophotonics will not depend solely on advances in instrumentation. Rather, it will depend on our ability to transform complex optical data into clinically meaningful knowledge. In this context, AI is emerging as the critical bridge between photonic innovation and healthcare implementation, enabling robust, scalable, and clinically actionable solutions across a wide range of biomedical applications.

Prof. Jürgen Popp is a scientific director of the Leibniz Institute of Photonic Technology (IPHT) in Jena, Germany. He is a member of the German Academy of Science and Engineering, a Fellow of the Society for Applied Spectroscopy and a SPIE Fellow. His research focuses on the application of spectroscopic technology for medical diagnostics. He received the Robert Kellner Lecture Award in 2013. In 2018, Popp was awarded both the Berthold Leibinger Innovation Prize and the Kaiser Friedrich Research Prize, and in 2019 the Thuringian Research Prize. In 2023, he received the Charles Mann Award from the American Federation of Analytical Chemistry and Spectroscopy Societies for outstanding contributions in the field of spectroscopy.

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