AN ADVANCED MULTI-PARAMETRIC OCT ANGIOGRAPHY APPROACH FOR ASSESSING TREATMENT HETEROGENEITY IN PORT-WINE STAINS

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Abstract

Port Wine Stains (PWS) are congenital capillary malformations characterized by ectatic dermal microvasculature that often demonstrate variable and heterogeneous responses to laser and vascular-targeted therapies. Conventional clinical assessment methods, such as visual inspection and colorimetric evaluation, provide limited quantitative insight into microvascular remodeling following treatment. To address this limitation, this study proposes a multi-parametric Optical Coherence Tomography Angiography (OCTA)–based analytical framework to quantitatively assess and characterize heterogeneous therapeutic responses in PWS lesions.The proposed system integrates longitudinal OCTA-derived vascular and perfusion biomarkers, including vessel density (VD), vessel length density (VLD), vessel diameter index (VDI), tortuosity index (TI), fractal dimension (FD), branchpoint density (BPD), flow index (FI), perfusion density (PD), capillary dropout index (CDI), and intra-lesion heterogeneity metrics such as perfusion heterogeneity (PH) and flow heterogeneity (FH). By computing delta changes between baseline and follow-up sessions, the framework captures dynamic vascular remodelling patterns induced by therapy. A composite response score is formulated using weighted multi-parametric deltas to reflect improvements in perfusion enhancement, vascular normalization, and reduction in heterogeneity. To further quantify response diversity, unsupervised clustering is employed to identify latent responder subgroups without prior labelling, revealing distinct microvascular adaptation trajectories. Supervised machine learning models are then utilized to classify therapeutic outcomes and determine the most influential biomarkers driving response variability. Feature importance analysis highlights the critical role of flow-based parameters and heterogeneity reduction in distinguishing good responders from partial or poor responders. The proposed approach enables comprehensive lesion-level and patient-level evaluation, supporting objective monitoring across multiple treatment sessions. By integrating structural and functional vascular metrics, the framework captures both macroscopic improvement and microvascular normalization, providing a more nuanced understanding of therapeutic efficacy.