Early Diagnosis of Periodontal Disease using Multimodal Imaging

A. OVERVIEW/ABSTRACT

Periodontal diseases impose a significant health and economic burden, with annual treatment costs in the United States exceeding $4.4 billion. Beyond tooth loss, periodontitis can adversely affect systemic health. There is a growing emphasis on diagnosing and monitoring periodontitis ***before*** clinical signs manifest, since current clinical and radiographic methods primarily detect past damage and cannot predict future risk. Early detection is crucial for successful intervention, yet existing tools cannot determine disease activity in early stages. Thus, there is a strong need for cost-effective, rapid, and non-invasive biomarkers to detect periodontal and peri-implant disease at its onset.

Diffuse correlation spectroscopy (DCS) enables non-invasive measurement of microvascular blood flow, making it highly suited for detecting the hyperemia and angiogenesis that characterize early periodontal inflammation. Unlike conventional clinical tools, DCS can quantify perfusion changes in real time and at tissue depths relevant to gingival vasculature. Integrating DCS into an intraoral imaging platform allows for functional assessment of inflammation alongside structural changes, supporting earlier diagnosis and improved monitoring of treatment response in periodontal disease. Photoacoustic microscopy (PAM) provides high-resolution imaging of vascular structures based on optical absorption contrast, enabling precise visualization of gingival microvasculature. In periodontal inflammation, increased blood volume and vessel remodeling are early hallmarks that PAM can detect with superior spatial resolution compared to traditional imaging. When integrated into an intraoral device, PAM offers a powerful tool for non-invasively mapping inflammatory vascular changes, allowing early detection and longitudinal monitoring of disease progression or therapeutic response. High-frequency ultrasound (US) provides non-invasive, real-time imaging of periodontal soft tissues and alveolar bone with micrometer-scale resolution. It enables detection of subtle structural changes such as gingival thickening, periodontal pocket formation, and early alveolar bone loss that are not visible on conventional radiographs. As a radiation-free modality, US is well-suited for longitudinal monitoring and early detection of disease progression in both clinical and preclinical settings. Its integration into a multimodal probe enhances diagnostic precision by complementing functional imaging modalities. Thus, the **goal** of this project is to apply a multimodal imaging approach, combining optical, photoacoustic, and ultrasound imaging, in an experimental periodontitis model to determine whether inflammation and bone loss can be detected at early stages, enabling timely intervention. The complementary expertise of our team is well-suited for the successful completion of the proposed project. To implement this approach and achieve our goal, we will pursue these **Specific Aims (SAs):**

SA-1. Develop multimodal imaging probe for phantom validation. We will optimize a combined optical/photoacoustic/ultrasound imaging system for the properties of oral tissues, testing its contrast and sensitivity in tissue-mimicking phantoms. **Metrics for Success:** Completion of integrated probe assembly; co-registered imaging of phantom layers with axial resolution ≤ 50 μm; blood flow sensitivity validated in perfused phantoms; depth penetration of ~3 mm.

SA-2. Validate the multimodal imaging system in a rat model of periodontitis. We will use a lipopolysaccharide (LPS)-induced periodontitis model in rats to evaluate disease progression and correlate in vivo imaging findings with standard clinical and histological measures. **Metrics for Success:** Successful in vivo imaging across all disease stages; correlation ≥ 0.8 between imaging-derived metrics (vascular density, blood flow, bone levels) and histological/gold-standard measurements (e.g., CD31, MMP-9, μCT); ability to resolve early vascular changes prior to bone loss.

Impact/Outcome: The ability to identify disease activity before irreversible bone loss occurs could shift the standard of care from reactive to proactive intervention, improving long-term oral and systemic health outcomes. With particular relevance to geriatric populations among whom periodontitis is highly prevalent, this work directly supports the Stony Brook Healthy Aging program. It also fosters interdisciplinary collaboration between dental and biomedical engineering researchers, promoting translational research excellence. Ultimately, this platform could support precision oral healthcare, accelerate therapeutic development, and enhance Stony Brook's competitiveness for NIDCR and industry funding opportunities.

Innovation. This project introduces a novel intraoral imaging platform that uniquely integrates high-frequency ultrasound (US), photoacoustic microscopy (PAM), and diffuse correlation spectroscopy (DCS) into a single compact device for periodontal diagnostics. Unlike conventional imaging methods that assess structural changes or perfusion separately, this system enables co-registered, depth-resolved visualization of gingival vasculature, tissue architecture, and real-time blood flow. The proposed approach is the first to combine these three modalities for use in a small animal oral model, offering unprecedented multimodal insight into both early inflammatory responses and progressive bone loss. By enabling simultaneous structural and functional imaging in vivo, this innovation addresses a critical gap in the early detection and monitoring of periodontal disease.