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Non-Invasive High-Resolution Imaging in Oral Pathology: The Evolving Role of OCT and Mucoscopy in Inflammatory Lesion Differentiation

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Abstract

Introduction: The diagnosis and management of oral mucosal lesions, particularly Oral Lichen Planus (OLP), are transitioning toward non-invasive, high-resolution imaging to overcome the limitations of traditional biopsy. Optical Coherence Tomography (OCT) and mucoscopy have emerged as pivotal tools, offering real-time visualization of tissue microstructures.

Purpose: This review aims to evaluate the technical capabilities and clinical utility of OCT and mucoscopy in oral pathology. The study specifically examines their efficacy in differentiating inflammatory lesions, detecting early malignant transformations, and the burgeoning role of artificial intelligence (AI)—including Convolutional Neural Networks and Vision Transformers—in automating image interpretation.

Methodology: A comprehensive literature analysis was conducted to synthesize current evidence on surface and subsurface imaging characteristics, diagnostic accuracy, and the integration of machine learning algorithms to reduce inter-observer variability.

Results: Findings demonstrate that OCT excels in providing cross-sectional insights into epithelial thickness and basement membrane integrity, while mucoscopy offers superior visualization of surface morphological patterns, such as Wickham striae and vascular configurations. The integration of AI significantly enhances the speed and objectivity of these assessments, bridging the gap between clinical observation and histopathology.

Conclusion: The combined application of OCT and mucoscopy represents a paradigm shift in oral diagnostics, offering a synergistic approach to tissue analysis. While histopathology remains the gold standard, these non-invasive modalities improve diagnostic precision, facilitate targeted biopsies, and enable longitudinal monitoring. Future advancements in device portability and AI software integration are expected to solidify these technologies as essential components of routine clinical practice and personalized patient management.

Keywords: Oral Lichen Planus; Optical Coherence Tomography; Mucoscopy; Artificial Intelligence; Oral Pathology.

1. Introduction

Oral mucosal disorders, especially chronic inflammatory diseases such as Oral Lichen Planus (OLP), pose considerable diagnostic difficulties in everyday clinical settings. OLP exhibits a wide range of clinical presentations, including reticular, erosive, atrophic, and plaque-like forms, which frequently resemble other oral conditions such as leukoplakia, pemphigus vulgaris, and lichenoid reactions [1]. This clinical similarity limits the reliability of diagnosis based solely on

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visual inspection. Moreover, the established potential of OLP to undergo malignant transformation into Oral Squamous Cell Carcinoma (OSCC) underscores the importance of early identification and continuous surveillance [2].

Histopathological analysis obtained through biopsy has long been considered the diagnostic gold standard, as it allows detailed assessment of epithelial alterations, inflammatory cell infiltration, and basement membrane disruption. Nevertheless, repeated biopsies are invasive and may cause patient discomfort and procedural morbidity, particularly in vulnerable groups such as children and individuals with sensitive oral tissues [3]. In addition, biopsy accuracy may be compromised by sampling bias, as the selected site may not reflect the most pathologically representative area of the lesion, leading to diagnostic uncertainty or delayed recognition of dysplastic changes [4].

Recent advances in biomedical imaging have facilitated the development of non-invasive, high-resolution diagnostic techniques collectively described as optical biopsy. Among these, Optical Coherence Tomography (OCT) and mucoscopy (oral dermoscopy) have gained increasing attention for real-time, in vivo assessment of oral mucosal lesions [5]. OCT enables cross-sectional visualization of both epithelial and subepithelial structures at near-histological resolution without tissue excision, while mucoscopy provides enhanced evaluation of surface features, including vascular morphology, pigmentation patterns, and characteristic OLP findings such as Wickham striae [3].

2. Methodology

2.1. Study Design

This study employed a comprehensive literature review design to synthesize current evidence on the diagnostic efficacy of Optical Coherence Tomography (OCT) and mucoscopy in oral pathology.

2.2. Search Strategy

A systematic search was conducted across multiple electronic databases, including PubMed, ScienceDirect, Elsevier, Wiley Online Library, and Google Scholar. The search was focused on peer-reviewed articles, technical reports, and clinical trials published primarily between 2012 and 2023 to ensure the inclusion of recent technological advancements.

2.3. Keywords and Terms

The literature search utilized specific descriptors and Boolean operators, including "Optical Coherence Tomography," "Mucoscopy," "Oral Dermoscopy," "Oral Lichen Planus," and "Deep Learning in Oral Cancer."

2.4. Inclusion and Exclusion Criteria

Articles were selected based on their relevance to non-invasive oral imaging. Inclusion criteria prioritized studies providing structural validation of oral tissues, assessment of basement membrane integrity, and the application of Artificial Intelligence (AI) in image interpretation.

2.5. Data Synthesis and Analysis

The reviewed literature was categorized into three thematic areas:

- The technical capacity of OCT for subsurface architectural mapping and lesion depth measurement.
- The clinical utility of mucoscopy for surface morphology and vascular pattern recognition.
- The impact of AI integration (e.g., CNNs and Vision Transformers) on reducing inter-observer variability and improving diagnostic objectivity.

2.6. Evaluative Framework

The study evaluated these modalities against the current "gold standard" of histopathological examination to determine their potential for real-time clinical decision-making and longitudinal lesion monitoring.

2.7. Optical Coherence Tomography (OCT) in Oral Mucosa

Optical Coherence Tomography (OCT) is a non-invasive imaging modality that uses low-coherence interferometry to generate high-resolution, cross-sectional images of tissue architecture in real-time. Employing a low-coherence broadband near-infrared light source, OCT achieves high spatial resolution (approximately 20 μm), enables visualization of microstructural features of the oral mucosa without requiring excisional biopsy [6].

OCT can clearly delineate the individual layers of the oral mucosa, including the epithelium, basement membrane, and lamina propria. The epithelium appears as a relatively uniform reflective layer, while the basement membrane is seen as a thin hyper-reflective line separating the epithelium from the underlying connective tissue. OCT's ability to identify these layers in vivo provides detailed architectural information that cannot be reliably obtained through clinical examination alone [7].

In patients with Oral Lichen Planus, OCT can detect hallmark microscopic changes, such as epithelial thinning or thickening, surface hyper-reflectivity, and disruption or irregularity of the basement membrane. These features help differentiate OLP from other oral mucosal conditions, including leukoplakia or early malignancies. OCT also allows for quantitative assessment, such as measuring epithelial thickness and lesion depth, which is valuable for monitoring disease progression or response to therapy. Furthermore, OCT can guide targeted biopsies, minimizing sampling error by identifying the most representative area of the lesion, and can be repeated over time for longitudinal surveillance without subjecting patients to repeated invasive procedures [8]. The non-invasive nature of OCT, coupled with real-time imaging, makes it particularly useful in pediatric populations and patients with multiple or extensive lesions [9].

3. Mucoscopy (Oral Dermoscopy) for Surface Characterization

Mucoscopy, also referred to as oral dermoscopy, is a non-invasive imaging modality that enables detailed, high-resolution evaluation of the oral mucosal surface [10,11]. This technique assists clinicians in identifying specific morphological patterns and surface features associated with various oral diseases [12,13]. In Oral Lichen Planus (OLP), mucoscopy can demonstrate characteristic findings such as Wickham striae, which present as delicate, white, reticular lines on the mucosa [11,14]. In addition, mucoscopy facilitates the assessment of vascular characteristics, including capillary loop patterns, telangiectasia, focal erythema, and pigmentary changes that may reflect chronic inflammatory processes or early dysplastic alterations [15–17].

A key advantage of mucoscopy is its ability to aid in the differential diagnosis of OLP from other inflammatory or autoimmune oral mucosal disorders [18,19]. For instance, pemphigus vulgaris typically exhibits erosive lesions or flaccid bullae with distinct vascular features, whereas oral lichenoid drug reactions may display irregular pigmentation and less prominent Wickham striae [18,20]. Mucoscopy is also valuable in the evaluation of chronic cheilitis, which is characterized by diffuse erythema, scaling, and fissuring rather than the organized striated patterns seen in OLP [21]. Accurate differentiation using mucoscopy is essential for guiding appropriate clinical management and for minimizing unnecessary diagnostic or therapeutic interventions [22,23].

Recent technological innovations have further expanded the clinical utility of mucoscopy [15]. Contemporary oral dermatoscopes are equipped with adjustable viewing angles, ergonomic designs, and enhanced illumination, improving visualization of anatomically challenging regions such as the posterior oral cavity [12,15,24]. Furthermore, integration with digital imaging systems allows high-resolution image acquisition, storage, and longitudinal comparison of lesions over time [25,26]. Emerging features, including real-time measurement of striae dimensions and vascular density, may provide quantitative indicators of disease activity and treatment response, thereby strengthening the role of mucoscopy in both diagnosis and longitudinal monitoring [17,27].

4. Comparative Efficacy and Synergistic Use

Optical Coherence Tomography (OCT) and mucoscopy play complementary roles in the assessment of oral mucosal lesions by providing information from different tissue levels [28]. OCT is particularly effective in evaluating lesion depth and subsurface architecture, including epithelial thickness and basement membrane integrity, which are critical parameters for detecting dysplasia and early malignant transformation [29]. In contrast, mucoscopy offers superior visualization of surface characteristics, enabling detailed assessment of Wickham striae, vascular configurations, pigmentation, and subtle mucosal alterations [15,30]. While OCT primarily supports structural and depth-related analysis, mucoscopy excels in surface pattern recognition, rendering both modalities valuable for a comprehensive diagnostic approach [6,28].

Recent developments in machine learning (ML) and deep learning (DL) have facilitated automated interpretation of high-resolution images obtained from OCT and mucoscopy [31,32]. Advanced algorithms, including convolutional neural networks (CNNs) and Vision Transformers (ViT), can be trained to identify imaging patterns associated with Oral Lichen Planus (OLP) and other oral mucosal pathologies [32,33]. The integration of artificial intelligence (AI) enables rapid, objective, and reproducible image analysis, thereby reducing inter-observer variability and supporting real-time clinical decision-making [31,34]. Furthermore, AI-assisted systems may assist in lesion triage, identification of high-risk regions requiring biopsy, and detection of subtle longitudinal changes that may be difficult to recognize through visual assessment alone [26,33].

When applied in combination, OCT and mucoscopy offer a synergistic diagnostic strategy [3,30]. OCT delineates subsurface tissue architecture and lesion depth, while mucoscopy evaluates surface morphology and vascular patterns [5,15,28]. This dual-layer assessment enhances diagnostic confidence, supports targeted biopsy planning, and improves non-invasive monitoring of lesion progression over time [3,6]. Emerging evidence suggests that the combined use of these imaging modalities may achieve diagnostic performance approaching that of histopathological examination for selected lesion types; however, biopsy remains the gold standard for definitive diagnosis [3,30].

5. Clinical Implications and Future Directions

One of the most important clinical applications of Optical Coherence Tomography (OCT) and mucoscopy is their role in guiding biopsy procedures [28]. By providing real-time, high-resolution visualization of both surface morphology and subsurface tissue architecture, these imaging modalities enable clinicians to identify the most diagnostically representative areas for tissue sampling [35]. This imaging-guided approach reduces the risk of sampling error, a well-recognized limitation of conventional biopsies in which non-representative specimens may result in misdiagnosis or delayed detection of dysplastic changes. In addition, targeted biopsies supported by non-invasive imaging can minimize unnecessary tissue removal, thereby reducing patient discomfort and procedural morbidity.

OCT and mucoscopy also facilitate longitudinal monitoring of chronic oral mucosal conditions such as Oral Lichen Planus (OLP) [35]. Serial imaging allows assessment of temporal changes in epithelial thickness, vascular architecture, and striae morphology, which are relevant indicators of disease activity and progression. This approach is particularly important for the early identification of malignant transformation into Oral Squamous Cell Carcinoma (OSCC) [36]. The non-invasive nature of these techniques permits repeated evaluations without the need for multiple biopsies, making them suitable for long-term surveillance, especially in pediatric patients and individuals at increased risk of malignant progression.

The integration of OCT and mucoscopy with artificial intelligence (AI) further enhances diagnostic efficiency and reproducibility [37]. Machine learning and deep learning models have demonstrated the ability to automatically recognize imaging features associated with OLP, track lesion evolution over time, and identify regions suggestive of higher malignant [38]. This automated analysis reduces observer-dependent variability and supports clinicians in prioritizing clinical decision-making rather than manual image interpretation.

Looking ahead, these imaging modalities are expected to play an increasingly important role in non-invasive screening and longitudinal surveillance of oral mucosal lesions. Ongoing research focuses on improving image resolution, device portability, and seamless software integration for AI-assisted diagnostics [39]. Advances in illumination and ergonomics are also expected to improve visualization of posterior oral regions and anatomically complex sites. Furthermore, combining OCT and mucoscopy with other emerging imaging technologies, such as confocal laser endomicroscopy and multispectral imaging, may provide multi-layered diagnostic information and further reduce reliance on invasive biopsy procedures [40].

6. Conclusion

Optical Coherence Tomography (OCT) and mucoscopy represent a paradigm shift in the current diagnostic workup in Oral Pathology. OCT helps in a thorough assessment of the subsurface architecture, whereas mucoscopy allows for a meticulous analysis of the surface topography. Their complementary use, especially when combined with AI-driven analysis, enhances diagnostic accuracy, guides targeted biopsies, and enables longitudinal monitoring of conditions like OLP. Although the current gold standard in Oral Pathology diagnosis is Histopathological examination, these modalities are all set to become core tools in diagnosing Oral Mucosal Diseases.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no conflict of interest.

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