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REVIEW ARTICLE

INNOVATIONS IN EARLY DETECTION OF ORAL AND MAXILLOFACIAL CANCERS: A SCOPING REVIEW OF ADVANCED DIAGNOSTIC APPROACHES

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Abstract

Background: Early detection of oral and maxillofacial cancers substantially improves patient outcomes and reduces treatment-related morbidity. Despite conventional methods such as visual examination and biopsy, late-stage diagnosis remains prevalent, emphasizing the need for advanced diagnostic strategies.
Objective: This scoping review synthesizes current evidence on innovative diagnostic approaches for oral and maxillofacial malignancies, highlighting methods that enhance early detection, diagnostic accuracy, and clinical decision-making.
Methods: A comprehensive literature search was conducted following PRISMA-ScR guidelines across PubMed, Scopus, Web of Science, and Cochrane Library databases. Studies reporting on imaging modalities, molecular diagnostics, light-based detection systems, salivary biomarkers, digital pathology, and artificial intelligence (AI) in oral and maxillofacial cancer diagnosis were included. Data were extracted on diagnostic performance, clinical utility, andlimitations.
Results: A total of 214 articles were identified, with 110 studies of high methodological quality selected for synthesis. Advanced imaging modalities—including MRI, CBCT, PET/CT, and ultrasonography—provide detailed anatomical and functional assessment. Non-invasive approaches, such as salivary biomarkers, chemiluminescence, autofluorescence spectroscopy, and confocal laser endomicroscopy (CLE), improve early lesion detection.
AI and digital pathology enhance predictive diagnostics, histopathological interpretation, and workflow efficiency. These emerging technologies demonstrate promise in overcoming limitations of traditional methods, though standardization, accessibility, and clinical validation remain challenges.
Conclusion: Integrating advanced imaging, molecular diagnostics, light-based detection, salivary biomarkers, and AI-assisted analysis represents a paradigm shift in early diagnosis of oral and maxillofacial cancers. These innovations have the potential to reduce diagnostic delays, optimize treatment planning, and improve patient outcomes. The clinical and economic significance of timely diagnosis underscores the importance of adopting comprehensive, state-of-the-art diagnostic strategies.

Keywords: Oral cancer, Maxillofacial neoplasms, Early detection, Advanced diagnostics, Artificial intelligence, Salivary biomarkers, Imaging, Confocal laser endomicroscopy

INTRODUCTION

Despite the good visualization of the maxillofacial region, the number of new cases of neoplasms is constantly increasing [1]. Neoplasms in this area are among the most complex socio-medical problems, and several developmental trends have been observed [2–4]. The uniqueness of the anatomical structures in this region often necessitates large-scale destructive interventions, which complicates treatment and subsequent rehabilitation.

Since early diagnosis improves the prognosis of successful therapy, late or delayed diagnosis is a major factor contributing to the low survival rate of cancer patients. Detection of malignant tumors in the maxillofacial area should be an integral part of therapeutic and dental examinations, as early diagnosis is critical. Unfortunately, malignant tumors in this region are, in most cases, not diagnosed until they have spread to the lymph nodes [5,6].

Considering that individual parts of the oral cavity, oropharynx, face, and facial bones have characteristic features that affect the clinical course of the tumor process, it is necessary to account for the following primary tumor localizations: mucous membranes of the oral cavity, tongue, upper jaw, lower jaw, upper lip, lower lip, salivary glands, facial skin, and scalp [7–9].

Tumors of any histological type can occur in the tissues of the oral cavity, face, and facial bones [10]. By origin, tumors may arise from connective tissue, epithelium, muscle, nervous tissue, or other tissues. In some cases, mixed tumors are found, consisting of several tissue types. The origin of odontogenic tumors is associated with the development of the dental system. Some of these formations are conditionally classified as tumors, as they represent a threshold for the development of blood vessels or skin, such as certain types of angiomas or pigmented birthmarks [11,12].

From this perspective, it is necessary to distinguish true tumors from tumor-like diseases. In the facial and jaw regions, there are primary tumors and secondary tumors, the latter being metastases from primary foci located in other parts of the body [13]. Metastases to the face and jaws are typically observed in the late stages of malignant tumor development, when the disease has generalized [14].

The leading complaint in malignant tumors is progressive disruption of the form or function of an organ, with the pathological process extending to neighboring organs and tissues. This is often accompanied by ulceration at the tumor site and changes in regional, and less often distant, lymph nodes [15].

As the disease progresses, especially in cancers of the oral cavity, local spontaneous pain appears and intensifies, which increases patient suffering and often requires radiotherapy. Additionally, there is gradual deterioration of the patient's general condition, including loss of appetite, weight loss, and weakness. Patient histories frequently reveal precancerous conditions preceding tumor appearance, such as dyskeratosis, chronic inflammatory processes, long-term non-healing ulcers or fissures, and pigment spots [16–19].

Early detection of oral cancer requires regular screening of the oral cavity and maxillofacial area. The introduction of advanced diagnostic methods in the evaluation of malignant neoplasms in this region ultimately leads to earlier detection, more effective treatment strategies, and reduced mortality associated with this pathology. The current standard for diagnostics and detection of neoplasms in the oral and maxillofacial region is based on clinical visual screening, histological examination of biopsy material, and genetic methods. Advances in digital technology,immunohistochemistry, immunofluorescence, and artificial intelligence have played an important role in the early diagnosis of malignant neoplasms in this area. Alongside the pathologist, who remains fundamental in cancer diagnosis, these methods will increasingly become part of the routine diagnosis and management of cancer patients.

This scoping review synthesizes current evidence on innovative diagnostic approaches for oral and maxillofacial malignancies, highlighting methods that enhance early detection, diagnostic accuracy, and clinical decision-making.

2. METHODOLOGY

2.1 Comprehensive Search Strategy

A systematic review was conducted to identify articles on the diagnostic evaluation of head and neck cancers. Searches were performed in Google Scholar, MDPI, Scopus, Web of Science, and PubMed. A total of 214 articles were identified, of which 110 studies of high methodological quality were selected for synthesis according to the PRISMA guidelines (Figure 1).

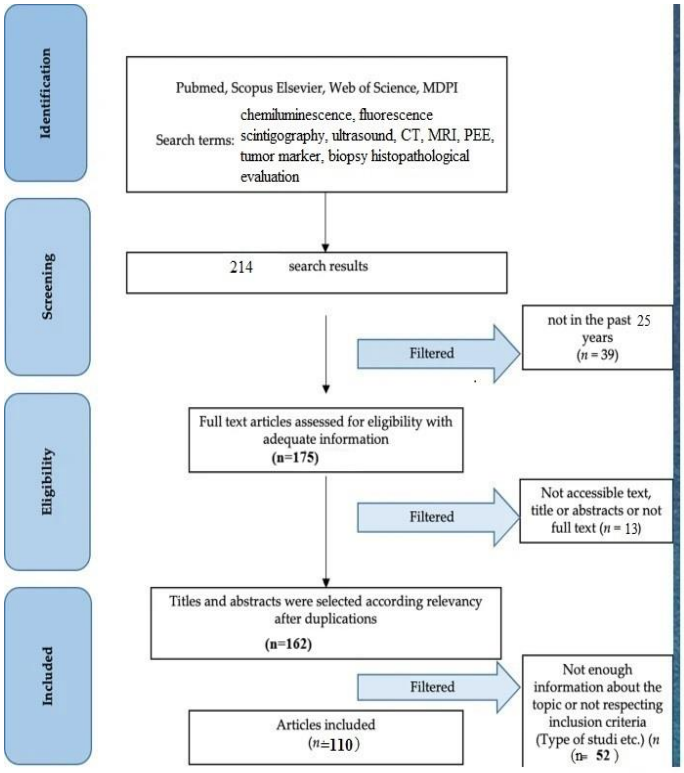

Figure 2. PRISMA Flow Diagram

2.2 Study Selection

Reviewer DM screened the titles and abstracts of all identified studies to determine eligibility based on predetermined inclusion and exclusion criteria. Studies deemed potentially eligible underwent full-text review. Any discrepancies between reviewers were resolved through discussion. Reviewers also identified and documented threats to the validity of each study, including errors in study execution or poor measurement.

2.3 Inclusion and Exclusion Criteria

Inclusion criteria: Studies were selected if they met the following MeSH criteria:

- **Design:** Randomized assignment of participants.
- **Participants:** Any cancer patient undergoing surgery, chemotherapy, or radiation therapy.
- **Diagnostics:** Toluidine blue staining, light detection methods, chemiluminescence, fluorescence, scintigraphy, ultrasound, X-rays, CT, MRI, positron emission tomography (PET), tumor markers, biopsy, and/or histopathological evaluation.
- **Language:** Articles written in English.

No restrictions were applied regarding minimal quality, sample size, or number of patients.

Exclusion criteria:

Unpublished studies, conference abstracts, letters to the editor, case reports, and in vitro or in vivo animal experimental studies were excluded to reduce publication bias. The effectiveness of diagnostic methods was evaluated by synthesizing relevant outcome data extracted from selected studies.

2.4 Data Extraction

Two reviewers independently extracted data from the included studies using a standardized data extraction form. Reviewers also identified and documented threats to validity, including errors in study execution or measurement bias.

2.5 Quality Assessment

Effectiveness was assessed by synthesizing relevant outcome data from the selected studies, focusing on reduction of cancer incidence and cancer-related mortality.

2.6 Data Synthesis

The results of this review were reported following PRISMA guidelines. A narrative synthesis of findings was provided.

2.7 Effect Measures

Effectiveness of diagnostic methods was primarily measured in terms of their ability to reduce cancer incidence and detect precancerous lesions. Reduction in population-level cancer incidence and cancer-specific mortality were used as key outcome measures.

3. RESULTS

This review highlights the modern achievements in diagnostic methods for tumors of the oral cavity and maxillofacial region. The most advanced methods identified include MRI, PET, tumor markers, fluorescein-stained confocal laser endomicroscopy (CLE), and immunohistopathological diagnostics. These findings can inform strategies to improve diagnostic efficiency and enhance preventive care, ultimately reducing complications in cancer patients.

Late detection of oncological processes in the maxillofacial region indicates persistent diagnostic deficiencies[20]. This underscores the need to improve diagnostic and preventive methods, as well as to raise the level of "oncological alertness" among both clinicians and patients.

3.1 Visual Screening and Early Detection

Visual oral examination (VOE) and palpation are first-line screening tools, followed by diagnostic adjuncts when suspicious lesions are detected:

Visual screening for oral cancer (VOE) involves:

- Examination of the oral cavity
- Palpation of suspicious lesions
- Assessment of lymph node enlargement

These are followed by diagnostic testing, including tissue staining with toluidine blue, autofluorescence spectroscopy, biopsy, and histopathological evaluation if indicated [21,22].

Several non-invasive tests have been proposed to supplement traditional diagnostic methods and improve accuracy[23,24]:

- Vital staining: toluidine blue, tolonium chloride

- Oral cytology: e.g., brush biopsy (OralCDx)
- Light detection: ViziLite, Microlux/DL, VELscope, Orascoptic DK, Identafi 3000
- Analysis of blood and saliva

In contrast, adult patients demonstrated reduced predictability, with expansion being primarily dentoalveolar and more susceptible to relapse

Table 1. Visual Screening Methods

Method	Purpose	Notes	References
Oral cavity examination	Detect visible lesions	First-line, subjective	[21,22]
Palpation	Assess lesion depth & consistency	May identify early tumors	[21,22]
Lymph node assessment	Detect metastasis	Part of standard VOE	[21,22]
Vital staining (toluidine blue, tolonium chloride)	Highlight dysplastic cells	Adjunctive, increases sensitivity	[23,24]
Oral cytology (brush biopsy, OralCDx)	Non-invasive tissue collection	Useful for early detection	[23,24]
Light-based detection (ViziLite, VELscope, Identafi 3000)	Detect epithelial dysplasia	Requires specialized equipment	[34–41]
Salivary and blood analysis	Early detection biomarkers	Non-invasive, cost-effective	[48–60]

3.2 Histopathological Evaluation

The gold standard for diagnosing oral squamous cell carcinoma (OSCC) remains the combination of visual examination and histological analysis of tissue biopsies [25].

Biopsy methods include:

- Surgical biopsy
- Puncture biopsy
- Endoscopic biopsy
- Lymph node biopsy
- Brush biopsy
- Needle aspiration biopsy

The choice of technique depends on lesion site, size, and suspected diagnosis. While highly informative, biopsies can have psychological impacts on patients [26]. Morphological diagnosis may also include PAS reaction, Van Gieson staining, Perls staining, and Congo red staining for differentiation [26,27]. Van Gieson staining highlights connective tissue, especially collagen fibers, in benign and malignant soft tissue tumors [28]. Advances in digital pathology allow histological, cytological, and immunohistochemical analysis of high-resolution whole-slide images (WSI) from biopsies or surgical resections[29].

Table 2. Biopsy Techniques and Applications

Technique	Indications	Advantages	Limitations	References
Surgical biopsy	Primary lesion	High diagnostic accuracy	Invasive, psychological impact	[26]
Punch biopsy	Small lesions	Minimal trauma	Limited tissue	[26]
Endoscopic biopsy	Hard-to-reach sites	Minimally invasive	Requires expertise	[26]
Lymph node biopsy	Suspected metastasis	Detects regional spread	Invasive	[26]
Brush biopsy	Non-invasive screening	Easy, repeatable	Lower sensitivity	[26]
Needle aspiration	Cystic/mass lesions	Minimally invasive	Cytology only	[26]

Complementary staining methods (Van Gieson, PAS, Perls, Congo red) enhance morphological differentiation between benign and malignant tissues [27,28]. Digital pathology allows high-resolution whole-slide imaging for histological, cytological, and immunohistochemical analysis [29].

3.3 Molecular Diagnostics and Tumor Markers

PIC reaction identifies acidic and neutral mucopolysaccharides in tissues, aiding in the diagnosis of leiomyosarcoma, mucoepidermoid carcinoma, and adenocarcinoma [30]. Perls staining detects ferric iron in tissues for lesions containing hemosiderin [31]. Non-invasive diagnostics also include salivary biomarkers, which can provide information on cancer presence, progression, and treatment response[^48–^60]. Saliva offers a simple, cost-effective, and non-invasive sample for early detection, screening, and monitoring of OSCC. Tumor markers provide insights into tumor prevalence, progression, prognosis, and postoperative monitoring [42–47]. Salivary markers such as **cytokines (IL-6, IL-8, TNF-α), defensin-1, p53, Cyfra 21-1**, and others show diagnostic potential [56–60]. However, no single marker has been universally validated for OSCC [61]. Molecular and immunohistochemical methods increase diagnostic precision.

Table 3. Molecular Diagnostic Methods

Method	Purpose	Sample Type	References
PIC reaction	Identify mucopolysaccharides	Tissue	[30]
Perls staining	Detect ferric iron	Tissue	[31]
Salivary biomarkers (IL-6, IL-8, TNF-α, p53, Cyfra 21-1)	Non-invasive early detection	Saliva	[48–60]
Confocal laser endomicroscopy (CLE)	In vivo histology	Tissue surface	[101]

3.4 Digital Imaging and Radiology

Digital innovations have transformed oral and maxillofacial diagnostics since the 1990s. **Digital X-rays** offer higher resolution with reduced radiation [62]. **CBCT** enables accurate bone assessment and density evaluation, though with lower soft tissue contrast [67–72].

MRI provides superior soft tissue contrast and functional imaging capabilities [73–78]. **CT** is rapid and accessible but requires ionizing radiation and contrast media.

SPECT and **PET/CT** allow metabolic and functional tumor assessment, improving staging and treatment monitoring [80–88].

Ultrasonography evaluates superficial lesions and guides needle aspiration biopsies, with intraoral USG assessing tumor thickness and vascularity [89,90].

Radiomics extracts quantitative imaging biomarkers for predictive modeling [92–94]. Advanced imaging provides anatomical, functional, and metabolic data:

Table 4. Imaging Modalities in Oral/Maxillofacial Tumors

Modality	Strengths	Limitations	References
Digital X-ray	High-resolution bone imaging	Limited soft tissue contrast	[62]
CBCT	Bone assessment, 3D reconstruction	Low soft tissue contrast	[67–72]
MRI	Superior soft tissue contrast, functional imaging	Expensive, contraindications	[73–78]
CT	Rapid, accessible	Radiation exposure	[73–78]
PET/SPECT	Metabolic activity assessment	Expensive, radiation exposure	[80–88]
Ultrasonography	Superficial lesion evaluation, biopsy guidance	Limited depth penetration	[89,90]

Radiomics and AI-based analysis allow predictive modeling and quantitative imaging biomarkers [92–100].

3.5 Light-Based Detection Systems

Chemiluminescence and **autofluorescence spectroscopy** enhance the screening of epithelial tissues [34–41].

- **Chemiluminescence**: blue-white light reflects off dysplastic and neoplastic cells, enabling early detection[37–39].
- **Autofluorescence**: loss of green autofluorescence indicates neoplastic changes, visualized as dark spots against normal tissue [40,41].

Table 5. Light-Based Detection Systems

Method	Principle / Mechanism	Advantages	Limitations	References
Chemiluminescence	Blue-white light reflects off dysplastic and neoplastic cells	Enhances early lesion detection; non-invasive	May give false positives; requires proper clinician training	37–39
Autofluorescence Spectroscopy	Loss of green autofluorescence indicates neoplastic changes, visualized as dark spots against normal tissue	Non-invasive; highlights precancerous or neoplastic areas	Interpretation can be subjective; limited tissue penetration depth	40,41

3.6 Artificial Intelligence (AI) in Diagnostics

AI enables predictive diagnostics, early detection, treatment planning, and decision support in oncology[95–100]. Deep learning applied to histological sections enhances accuracy and reduces observer variability. Limitations include data volume requirements and algorithm optimization.

Other emerging non-invasive technologies include **confocal laser endomicroscopy (CLE)** and **infrared thermal imaging**, which provide rapid intraoperative histological assessment [101].

Table 6. AI and Emerging Non-Invasive Technologies

Technology	Principle / Mechanism	Advantages	Limitations	References
Deep Learning on Histological Sections	Automated analysis of whole-slide images for pattern recognition	Improves diagnostic accuracy; reduces observer variability; supports predictive modeling	Requires large datasets; potential bias; algorithm optimization needed	[95–100]
Confocal Laser Endomicroscopy (CLE)	High-resolution in vivo microscopy for intraoperative tissue assessment	Rapid, real-time tissue evaluation; minimally invasive	Limited availability; requires specialized training	[101]
Infrared Thermal Imaging	Detects temperature variations associated with tissue metabolic activity	Non-contact, real-time detection; adjunct to other imaging modalities	Limited specificity; influenced by ambient conditions	[101]

3.7 Risk of Bias Assessment

The methodological quality and potential bias of the included studies were evaluated using the **QUADAS-2 tool** for diagnostic accuracy studies and adapted criteria for emerging technologies. Key domains assessed included:

- **Patient selection**: representativeness and inclusion/exclusion criteria
- **Index test**: clarity of methodology and blinding
- **Reference standard**: appropriateness and independent verification
- **Flow and timing**: completeness of data and interval between index test and reference standard
- **Reporting bias**: selective outcome reporting

A total of **110 studies** were assessed for risk of bias. Overall, conventional imaging studies (CBCT, MRI, CT) and AI-assisted diagnostics demonstrated moderate to low risk of bias, while studies on emerging non-invasive methods (salivary biomarkers, CLE, infrared thermal imaging) exhibited higher variability due to smaller sample sizes, lack of standardized protocols, and incomplete blinding.

Table 7. Risk of Bias Summary by Diagnostic Modality

Diagnostic Modality	Number of Studies	Low Risk	Moderate Risk	High Risk	Common Sources of Bias
Visual Oral Examination / Biopsy	22	12	8	2	Selection, reporting [21–28]
Light-Based Detection (Chemiluminescence, Autofluorescence)	18	7	9	2	Observer interpretation, sample size [34–41]
Molecular Diagnostics / Salivary Biomarkers	20	5	10	5	Small cohorts, protocol variability [48–60]
Advanced Imaging (CBCT, MRI, PET/CT, US)	25	18	6	1	Flow/timing, incomplete blinding [62–94]
AI and Digital Pathology	25	15	8	2	Dataset size, algorithm transparency [95–100]
Emerging Technologies (CLE, Infrared Imaging)	10	3	5	2	Training, accessibility, small sample [101]

3.8 Access to Care and Early Diagnosis

Timely access to primary care is crucial for early cancer detection[^103–^106]. Barriers include financial, geographic, sociocultural, and systemic factors. National cancer control plans should prioritize early detection, equitable access, and integration of advanced diagnostic methods.

Early detection reduces healthcare costs and improves outcomes. For example, in developed countries, early-stage cancer treatment costs are 2–4 times lower than treatment of advanced-stage disease[^107]. Improved early diagnosis has also been linked to significant reductions in mortality, as seen in breast cancer programs in the UK[^108].

Algorithm: Access to Care and Early Diagnosis

1. **Patient Presentation / Risk Assessment**
   - Identify high-risk individuals (tobacco/alcohol use, HPV infection, family history, previous lesions).
   - Conduct initial screening at primary care or dental visits.
2. **Visual Oral Examination (VOE)**
   - Inspect oral cavity for lesions.
   - Palpate suspicious areas and regional lymph nodes.
   - Document findings and risk level.
3. **Adjunctive Non-Invasive Tests (if indicated)**
   - Vital staining (toluidine blue, tolonium chloride).
   - Light-based detection (ViziLite, VELscope, autofluorescence).
   - Salivary or blood biomarker analysis (IL-6, IL-8, p53, Cyfra 21-1).
4. **Referral for Diagnostic Confirmation**
   - Refer to maxillofacial specialist or oncology center.
   - Schedule biopsy (surgical, punch, endoscopic, needle aspiration, or brush biopsy).
   - Conduct histopathology and molecular diagnostics.
5. **Advanced Imaging (if lesion confirmed/suspicious)**
   - CBCT, MRI, or CT for anatomical evaluation.
   - PET/SPECT for functional/metabolic assessment.
   - Radiomics and AI-assisted analysis for staging and treatment planning.
6. **Early Intervention & Treatment Planning**
   - Based on lesion type, size, stage, and patient health status.
   - Integrate multidisciplinary approach (surgery, radiotherapy, chemotherapy).
7. **Follow-Up and Monitoring**
   - Schedule routine follow-ups for recurrence or progression.
   - Use non-invasive tools (saliva biomarkers, light-based imaging, AI-assisted evaluation) for monitoring.
8. **Address Barriers to Access**
   - Identify and mitigate socioeconomic, geographic, and cultural barriers.
   - Implement telemedicine or outreach programs if necessary.
   - Ensure national cancer control guidelines support early detection programs.

4.DISCUSSION

The early detection and accurate diagnosis of oral and maxillofacial cancers remain a critical challenge in clinical practice. Despite the availability of conventional diagnostic approaches such as visual oral examination, palpation, and tissue biopsy, late diagnosis continues to contribute to poor prognosis and increased morbidity in affected patients[20]. This review demonstrates that advances in both non-invasive and imaging-based diagnostic methods have the potential to significantly improve early detection, risk stratification, and treatment planning.

Visual oral examination (VOE) and palpation remain the first-line assessment tools for identifying suspicious lesions in the oral cavity. While these methods are inexpensive and widely accessible, they are limited by their subjective nature and dependence on clinician expertise[21,22]. To overcome these limitations, adjunctive techniques such as vital staining (toluidine blue), oral cytology (e.g., brush biopsy), and light-based detection systems (ViziLite, VELscope, autofluorescence spectroscopy) have been increasingly adopted[23,24]. These approaches enhance the sensitivity and specificity of screening, enabling the identification of precancerous lesions that may be missed during conventional examination. Histopathological evaluation remains the gold standard for definitive diagnosis of oral squamous cell carcinoma (OSCC)[25]. Various biopsy techniques—including surgical, puncture, endoscopic, and needle aspiration biopsies—allow tissue sampling from the primary lesion or regional lymph nodes[26]. The choice of biopsy method depends on the lesion's location, size, and suspected pathology, with each technique presenting distinct advantages and potential psychological impacts on patients[26]. Complementary staining methods, such as Van Gieson, PAS, Perls, and Congo red, contribute to more precise morphological differentiation and characterization of tumor tissues[27,28].

Recent technological advances in molecular diagnostics, including immunohistochemistry and confocal laser endomicroscopy, have further refined diagnostic accuracy[29-31]. These methods provide rapid, high-resolution visualization of tissue architecture, molecular markers, and cellular morphology, facilitating the early detection of malignancy and the differentiation of benign from malignant lesions. Non-invasive assessment of biomarkers in saliva and blood also offers promising avenues for early cancer detection, with over 100 salivary biomarkers, including cytokines, p53, and Cyfra [21-1], demonstrating potential utility in OSCC screening50-60. Saliva-based diagnostics are advantageous due to their non-invasive nature, cost-effectiveness, and feasibility for repeated testing. Advanced imaging modalities, including CBCT, MRI, CT, SPECT, and PET, provide critical anatomical and functional information for tumor staging, treatment planning, and postoperative monitoring[62-88]. MRI is particularly valuable for its superior soft tissue contrast and ability to detect perineural and intracranial invasion[73-78], while PET offers functional assessment by differentiating metabolically active neoplastic tissue from normal structures[85-88]. Despite their advantages, imaging techniques have inherent limitations, including radiation exposure (CT, PET), contraindications (MRI), and interpretive variability. Radiomics and artificial intelligence (AI) have emerged as transformative tools in this context, enabling quantitative image analysis, predictive modeling, and automated histopathological interpretation [92-100]. AI-assisted diagnostics can integrate imaging, histological, and molecular data to support clinical decision-making, improve early detection rates, and optimize personalized treatment planning[95-98].

Despite these advances, challenges remain. Access to diagnostic services is uneven, particularly for socioeconomically disadvantaged populations, contributing to delays in presentation and treatment[103-105]. Moreover, the lack of standardized protocols for biopsy preparation, imaging acquisition, and AI training datasets can affect diagnostic consistency and accuracy[100]. Addressing these barriers requires the integration of technological innovation with public health strategies, including education, equitable access to care, and the implementation of national cancer control programs[106-110].

CONCLUSION

In conclusion, the integration of advanced imaging, molecular diagnostics, salivary biomarkers, and AI-assisted analysis represents a paradigm shift in the early detection and management of oral and maxillofacial cancers. These approaches have the potential to reduce diagnostic delays, improve patient outcomes, and decrease the economic burden associated with late-stage disease. Ongoing research and clinical validation are essential to optimize these tools, establish standardized protocols, and ensure their effective implementation in diverse healthcare settings. The clinical and economic importance of early diagnosis and optimal treatment selection necessitates the adoption of advanced cancer diagnostic technologies. Clear aligner therapy has demonstrated substantial efficacy in achieving maxillary arch expansion, particularly within the premolar region. The transition from uncontrolled tipping to predictable

translation is facilitated by advanced hybrid protocols like Smartee S11, which optimize force delivery through palatal pressure ridges. To ensure clinical success, practitioners should implement digital over-correction (10–20%) and utilize targeted auxiliaries to compensate for posterior resistance.

DECLARATIONS

Consent for publication

Not applicable.

Conflicts of interest

The authors have no conflicts of interest regarding this investigation**.**

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Ethical Approval

"Not applicable"

Consent for publication

"Not applicable"

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