# Evaluation of Diagnostic Imaging Techniques for Early Detection and Accurate Staging of Oral Squamous Cell Carcinoma (OSCC)

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## ABSTRACT

Oral squamous cell carcinoma (OSCC) represents a prominent malignancy of the oral cavity, posing a significant health burden worldwide. Timely detection and precise staging are essential determinants for efficacious management strategies, promoting improved patient outcomes. A multitude of diagnostic imaging modalities has been employed to serve these purposes, each endowed with distinctive benefits and inherent limitations. This study provides a comprehensive evaluation and comparison of the major imaging techniques used for OSCC detection and staging, including computed tomography (CT), magnetic resonance imaging (MRI), positron emission tomography (PET), ultrasound (US), and cone-beam computed tomography (CBCT), The review highlights CT as the primary modality for initial OSCC evaluation, given its ability to delineate the tumor's extent, lymph node involvement, and invasion into adjacent structures. MRI emerges as superior for assessing soft tissue invasion due to its higher resolution, despite its comparative inferiority for bone assessment. PET, often coupled with CT, furnishes functional insights into the tumor, playing a crucial role in evaluating therapeutic responses, recurrence, and metastasis. US is instrumental in diagnosing cervical lymph node metastasis—a major prognostic factor in OSCC—and assessing the primary tumor thickness. CBCT, a prevalent tool in dental practices, and panoramic radiography provide valuable views of dental structures and broad overviews of oral structures, respectively, albeit with varying degrees of precision and detail. Scintigraphy, while less common due to advancements in other techniques, retains relevance for certain clinical scenarios. The selection of an appropriate imaging modality hinges on several factors, encompassing tumor characteristics, patient health, and resource availability. Often, multiple imaging techniques are integrated for a comprehensive disease overview.

# Introduction

The concept of machine Oral health plays an integral role in the overall health of an individual. The oral environment is complex and consists of various structures, including teeth, tongue, salivary glands, and the mucosal lining [1], [2]. The health of the oral environment is influenced by numerous factors including microbial activity, personal habits, diet, and systemic health. This environment is also home to a diverse array of microorganisms, including bacteria, fungi, and viruses, collectively known as the oral microbiome. The interaction of these organisms with the host cells contributes to both oral health and disease. Saliva, produced by the salivary glands, is another key element in maintaining oral health. It contains essential enzymes, antibodies, and other compounds that protect oral tissues against microbial invasion and neutralize acids produced by bacteria, thus playing a crucial role in preventing tooth decay and gum disease [3].

Squamous cells are a type of epithelial cell, characterized by their flat shape resembling a fish scale [2]. These cells are present in various parts of the body, including the surface of the skin, the lining of the respiratory and digestive tracts, and the oral cavity. In the context of the oral cavity, squamous cells form the mucosal lining that protects underlying tissues from mechanical damage and pathogenic invasion. They act as the primary barrier against the diverse microbial population present in the oral cavity. Furthermore, squamous cells also play a role in the production of keratin, a protective protein that provides resilience and waterproofing to the tissues. The continuous turnover of squamous cells in the oral cavity is a crucial process for maintaining the integrity of the oral environment [4].

Oral Squamous Cell Carcinoma (OSCC) is a type of cancer that arises from squamous cells in the oral cavity [5]. OSCC represents a significant proportion of all head and neck cancers and is often associated with significant morbidity and mortality. It is predominantly caused by the carcinogenic effects of tobacco and alcohol, though other factors like human papillomavirus (HPV) infection, poor oral hygiene, and chronic inflammation can also contribute. The development of OSCC involves multiple genetic alterations in squamous cells, which disrupts their normal growth and differentiation processes. The resultant uncontrolled proliferation of these altered cells leads to the formation of a malignant tumor [6].

OSCC affects the squamous cells in the oral cavity by causing alterations in their normal function and structure. The genetic mutations that drive the development of OSCC can lead to the loss of normal growth regulation in squamous cells. Instead of being regularly replaced as part of the normal epithelial turnover, these mutated cells proliferate uncontrollably, forming a mass of cells or a tumor. The cancerous cells can also invade into deeper tissues and spread (metastasize) to other parts of the body. Additionally, the transformation of squamous cells into malignant cells can disrupt the barrier function of the oral mucosa, increasing susceptibility to infections and other oral diseases [7].

Oral Squamous Cell Carcinoma (OSCC) has a complex etiology, with multiple risk factors contributing to its development. These include tobacco use, alcohol consumption, infection with human papillomavirus (HPV), poor oral hygiene, and other lesser-known factors [8].

Tobacco use, both smoking and smokeless, is one of the leading causes of OSCC. It contains numerous carcinogens such as polycyclic aromatic hydrocarbons, N-nitrosamines, and aromatic amines, which can induce DNA damage and mutations in the oral squamous cells, leading to uncontrolled growth and proliferation [9]. The risk of developing OSCC increases with the duration and intensity of tobacco use and is particularly high among individuals who start at a young age. Quitting tobacco can significantly reduce this risk, though the risk remains elevated for several years after cessation [10].

Alcohol consumption, particularly heavy and prolonged, is another significant risk factor for OSCC. Alcohol acts as a solvent, enhancing the penetration of tobacco carcinogens into the oral mucosa, thereby potentiating their carcinogenic effects. Furthermore, the metabolism of alcohol results in the formation of acetaldehyde, a potent carcinogen that can cause DNA damage and interfere with DNA repair mechanisms [11]. The combined use of tobacco and alcohol has a synergistic effect, markedly increasing the risk of OSCC compared to their individual effects[12] .

Infection with certain types of human papillomavirus (HPV), particularly HPV-16, is also associated with an increased risk of OSCC. HPV is a sexually transmitted virus, and its role in OSCC is thought to be related to oral sexual behaviors. HPV can integrate its DNA into the host cell's genome, leading to the expression of viral proteins that interfere with cell cycle regulation, thus promoting the uncontrolled growth of squamous cells and the development of cancer [13].

Poor oral hygiene, characterized by infrequent tooth brushing, lack of professional dental care, and use of ill-fitting dentures, can lead to chronic inflammation and oral infections, both of which can contribute to the development of OSCC. Chronic inflammation can induce DNA damage and promote a pro-carcinogenic microenvironment, while oral infections can alter the oral microbiome, leading to dysbiosis and further inflammation [15], [16].

Other lesser-known but potential contributing factors include dietary deficiencies, particularly of fruits and vegetables rich in antioxidants, and exposure to ultraviolet light, which is more relevant for lip cancers. Genetic predisposition, such as individuals with Fanconi anemia and dyskeratosis congenita, is also associated with a higher risk of developing OSCC [17]. The presence of oral potentially malignant disorders (OPMDs), such as leukoplakia and erythroplakia, also increases the risk of OSCC.

# Diagnostic Imaging Techniques

### *Computed Tomography (CT):*

Computed Tomography, often referred to as CT, is a well-established diagnostic imaging tool that leverages the technology of computer-processed combinations of multiple X-ray measurements taken from different angles to produce cross-sectional images of specific areas of a scanned object. In the context of oral cancer, this imaging technique plays a pivotal role in early detection and subsequent evaluations. When used as a primary investigative measure, CT scans yield valuable data about the primary tumor, its precise location, size, and the degree of its infiltration into adjacent tissues. In essence, it paints a high-resolution, three-dimensional picture of the tumor's structural characteristics, facilitating a comprehensive understanding of the malignancy [18].

When assessing the extent of oral cancer, CT proves itself particularly beneficial due to its high contrast resolution, which allows for a clear distinction between normal and pathological tissues. Its ability to differentiate between various tissue types and densities enables accurate detection of invasion into surrounding structures. These include critical anatomical sites like the mandible, maxilla, tongue, and pharyngeal wall, among others. Consequently, this information aids in staging the cancer, determining the tumor-node-metastasis (TNM) classification, which is a globally acknowledged standard in cancer staging, therefore playing an integral role in formulating appropriate treatment strategies [19].

Another crucial aspect of CT in oral cancer management is its potential in identifying lymph node involvement. The spread of cancer to regional lymph nodes significantly impacts the prognosis and survival rate of patients, thus necessitating their thorough examination. CT is capable of detecting both macroscopic and microscopic lymph node metastases, although its sensitivity is somewhat reduced for the latter. However, it can effectively display morphological changes in lymph nodes, such as enlargement or central necrosis, which are common indicators of metastatic involvement [20].

The utility of CT is not confined to just the diagnosis and staging of oral cancer; it is also an invaluable tool in preoperative planning and postoperative monitoring. For surgical planning, CT scans can guide the surgical approach by delineating the tumor's boundaries, its relationship with surrounding structures, and the degree of bone involvement if present. This information helps surgeons to plan the extent of resection, choose the most suitable reconstructive option, and minimize potential complications. Moreover, in cases where a prosthetic rehabilitation is anticipated, CT scans assist in implant placement planning, ensuring optimal functional and aesthetic outcomes [21].

In terms of post-treatment evaluation, CT scans can monitor the progression or regression of the disease, detect potential recurrences, and evaluate the consequences of therapeutic interventions. It is particularly useful in differentiating between post-treatment changes and recurrent disease, a distinction that is vital for subsequent management decisions. However, distinguishing post-radiotherapy changes from tumor recurrence can be challenging due to similar imaging characteristics. Advanced CT techniques like perfusion CT and dual-energy CT can provide additional valuable data in such cases, reinforcing CT's importance in the comprehensive management of oral cancer.

### *Magnetic Resonance Imaging (MRI)*

Magnetic Resonance Imaging (MRI) is a non-invasive diagnostic imaging modality that uses a powerful magnetic field and radio frequency pulses to generate detailed images of the human body. Unlike CT, it does not rely on ionizing radiation. In the context of oral cancer, MRI's superior soft tissue contrast resolution makes it an exceptional tool for evaluating the extent of tumor invasion into surrounding tissues, particularly the soft structures like muscles, nerves, and blood vessels.

One of the key advantages of MRI is its multiplanar imaging capability, enabling acquisition of images in any desired plane without the need for patient repositioning. This is especially useful for complex anatomical regions like the oral cavity, where the tumors often have irregular and complex forms, infiltrating multiple tissue types and planes. The high-resolution images produced by MRI effectively demarcate the borders of these tumors, thereby providing crucial insights into the tumor's extent, aggressiveness, and potential invasion paths. Consequently, this information is invaluable when formulating a precise and individualized treatment plan for patients.

While MRI is excellent for soft tissue imaging, it may be less useful than CT when it comes to assessing bony structures. CT, with its exceptional resolution of hard tissues, is better suited for detailing the involvement of the mandible or maxilla in oral cancer cases. However, MRI still has a role to play in bone assessment. While it may not capture the fine architectural details as accurately as CT, it is quite adept at identifying bone marrow involvement and differentiating between normal bone marrow and tumor infiltration, which can have significant implications on the treatment approach [22].

Furthermore, MRI can be leveraged to evaluate perineural spread (PNS), a characteristic finding in oral cancer wherein the tumor spreads along the nerve fibers. Detecting PNS is crucial as it can significantly impact the disease's prognosis and may alter the therapeutic strategy. Given its superior soft tissue contrast, MRI is more sensitive than CT for the detection of PNS, thereby providing a more comprehensive view of the disease's extent and possible progression pathways.

MRI is uniquely positioned to monitor the effects of therapy, detect potential recurrences, and assess post-treatment changes in the surrounding tissues. Its ability to differentiate between post-treatment fibrosis, a common outcome of radiation therapy, and tumor recurrence is particularly noteworthy. MRI's non-invasive nature, combined with its exceptional imaging capabilities, makes it an integral tool in managing oral cancer, complementing the data obtained from other imaging techniques like CT for a holistic and comprehensive assessment.

### *Positron Emission Tomography (PET):*

Positron Emission Tomography, or PET, is a nuclear medicine imaging technique that offers unique metabolic insights into the body's tissues and organs. Unlike MRI and CT, which predominantly provide anatomical and structural information, PET sheds light on the physiological processes happening within the tumor and its surrounding tissues. This is particularly valuable in oncology, as cancer cells typically exhibit altered metabolic activity compared to normal cells. When utilized in combination with CT (PET/CT), it combines the anatomical detail of CT scans with the functional data obtained from PET, resulting in a detailed image showcasing both the location and metabolic behavior of the tumor.

One of the most common applications of PET/CT in oral cancer is the evaluation of therapeutic response. The effects of various treatments such as chemotherapy, radiation therapy, or targeted therapy often result in changes in the tumor's metabolic activity before any changes in size or morphology become apparent on CT or MRI. PET/CT, by assessing this metabolic activity, can thus provide an early indication of the tumor's response to treatment. This enables clinicians to adjust the treatment plan promptly if a certain approach proves ineffective, minimizing unnecessary exposure to potentially harmful treatments [23].

Additionally, PET/CT holds great promise for detecting recurrence and metastasis in oral cancer. Tumor recurrence, a major concern in cancer management, is often associated with changes in metabolic activity. As such, PET/CT can identify these changes even when structural alterations are not yet discernible on CT or MRI. Similarly, it is highly effective in detecting distant metastases, an occurrence that significantly impacts patient prognosis and treatment planning. PET/CT can perform a whole-body scan in a single session, thus enabling an efficient and thorough metastatic workup [24], [25].

PET/CT is commonly used in conjunction with other imaging modalities to provide a comprehensive understanding of the tumor's status. By integrating the metabolic data from PET with the structural information from CT, and possibly MRI, clinicians can obtain a holistic view of the tumor, including its size, location, morphological features, metabolic activity, and extent of invasion. This integrative approach improves the accuracy of diagnosis, staging, and follow-up, and ultimately contributes to the optimal management of oral cancer.

Importantly, PET/CT has a significant role in patient stratification for personalized treatment strategies. By revealing the heterogeneity within the tumor in terms of metabolic activity, it can identify aggressive sub-regions within the tumor, guiding targeted biopsy and focused treatment. As such, PET/CT not only offers an accurate diagnostic and prognostic tool, but also paves the way for precision medicine in the context of oral cancer.

### *Ultrasound (US):*

Ultrasound (US) is a versatile, non-invasive imaging technique that uses high-frequency sound waves to create real-time images of the body's internal structures. In the context of oral squamous cell carcinoma (OSCC), one of the primary applications of ultrasound is in the evaluation of cervical lymph node metastasis. The status of the cervical lymph nodes is a crucial determinant of prognosis in OSCC, as lymph node involvement often signifies a more advanced stage of disease and is associated with a poorer outcome.

Ultrasound stands out for its ability to provide detailed images of the lymph nodes, detecting subtle changes in size, shape, and internal architecture, which can indicate metastatic involvement. Additionally, US can discriminate between solid and cystic structures and visualize vascular patterns within lymph nodes, which can aid in determining malignancy. One of the primary advantages of ultrasound is its ability to be used in real time, enabling immediate and direct evaluation of lymph nodes, a factor which can significantly expedite the diagnostic process.

The use of ultrasound is not limited to just lymph node evaluation; it is also employed to perform ultrasound-guided fine needle aspiration (FNA), a minimally invasive procedure that can confirm the presence of metastasis. In this procedure, under real-time ultrasound guidance, a fine needle is inserted into the suspicious lymph node, and a small sample of tissue is aspirated for cytological examination. The real-time imaging allows for precise targeting of the lymph node, which reduces the risk of complications and improves the diagnostic yield [26].

High-resolution ultrasound is another innovative application that is proving beneficial in the management of OSCC. It can be used to accurately measure the thickness of the primary tumor, a parameter that has been shown to correlate with the degree of tumor invasion and the risk of cervical lymph node metastasis. This information can provide valuable insights for surgical planning, helping surgeons to determine the appropriate extent of resection and whether a neck dissection is necessary.

### *Cone-beam computed tomography (CBCT):*

Cone-beam computed tomography (CBCT) is an advanced imaging modality that has revolutionized dental and maxillofacial imaging. As the name suggests, CBCT uses a cone-shaped beam of radiation, in contrast to the traditional fan-shaped beam used in conventional CT. This difference allows CBCT to capture a comprehensive, three-dimensional image of the area of interest in a single rotation, providing high-resolution images with a lower dose of radiation than conventional CT.

CBCT's ability to generate detailed 3D images of dental and maxillofacial structures makes it particularly suited to evaluating oral squamous cell carcinoma (OSCC) when it involves the mandible or maxilla. These bones can be infiltrated by the tumor, significantly influencing the patient's prognosis and treatment planning. CBCT can accurately depict the degree of bone invasion, showing the precise location and extent of the infiltration. These high-resolution images allow for precise measurement of the tumor and the affected bone, which can be crucial when planning surgical intervention.

In addition to assessing bone invasion, CBCT can also provide valuable information about the surrounding dental structures. In patients with OSCC, this can have important implications for treatment planning, particularly when considering surgical interventions and post-surgical reconstruction. For instance, in cases where the removal of the tumor may affect the patient's dental integrity, CBCT images can help plan for possible dental implants or prosthetics. Similarly, detailed images of the surrounding anatomical structures can help to minimize damage to nearby vital structures during surgery [27].

Another advantage of CBCT over other imaging modalities is its ability to differentiate between different types of bony tissues, such as cortical and cancellous bone. This feature can provide additional information about the nature of bone involvement in OSCC and may have implications for the choice of surgical approach. For instance, tumors invading the denser cortical bone may require different surgical techniques compared to those infiltrating the softer cancellous bone.

# Conclusion

This study offers a nuanced understanding of the multifaceted role imaging techniques play in the detection and staging of oral squamous cell carcinoma (OSCC), a predominant malignancy that continually challenges global health [28]–[30]. The research weaves together strands of scientific evidence to illuminate the utility, strengths, and weaknesses of five main imaging modalities, namely computed tomography (CT), magnetic resonance imaging (MRI), positron emission tomography (PET), ultrasound (US), and cone-beam computed tomography (CBCT), in the OSCC diagnostic landscape. This investigation underscores the intricate balance between available resources, individual patient health, and specific tumor characteristics necessary to select the most apt imaging technique or amalgam of techniques.

The supremacy of CT as an initial tool for OSCC evaluation is reflected in its robust capacity to map out the tumor's extent, lymph node involvement, and encroachment into neighboring structures. This information guides clinicians in planning a targeted treatment approach, thereby augmenting the odds for successful intervention. However, despite the pivotal role of CT in initial OSCC assessment, our research has identified that no single imaging technique can wholly encapsulate the complex nature of OSCC [31], [32].

MRI emerges as a quintessential tool when probing soft tissue invasion, a critical parameter in OSCC staging. It provides unmatched soft tissue resolution that surpasses the capabilities of CT, facilitating a meticulous examination of tumoral spread in these tissues. However, it must be recognized that MRI falls short in evaluating bone invasion—an area where CT continues to reign. Thus, the study reinforces the idea that in the context of OSCC management, optimal patient care often necessitates employing a combination of imaging modalities to capture the complete disease landscape [33], [34].

PET scanning, routinely employed in tandem with CT, supplements the anatomical data garnered through CT with a metabolic perspective of the tumor. This fusion of information is indispensable in assessing therapeutic responses, flagging recurrence, and detecting metastasis, all of which hold significant implications for patient prognosis and management.

Meanwhile, ultrasound plays a particularly significant role in diagnosing cervical lymph node metastasis, a critical prognostic factor in OSCC. It also aids in gauging primary tumor thickness, complementing the information gathered by other imaging techniques. CBCT and panoramic radiography, often applied in dental practices, are highlighted as valuable tools for assessing oral and dental structures. However, these techniques should be seen as providing an overview and can't substitute for the detailed insight offered by modalities like CT or MRI. Notwithstanding the advancements made in imaging technologies, the study recognizes that scintigraphy, while less popular, remains a pertinent option in certain clinical scenarios, reinforcing the concept that choice of imaging modality is multifactorial.

The selection should be guided by a nuanced understanding of each technique's strengths and weaknesses in light of patient health, resource availability, and tumor characteristics. Furthermore, the study suggests that future research should aim to optimize the integration of these modalities, which could pave the way for more comprehensive, and therefore more effective, diagnostic and treatment strategies for OSCC.

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