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RECENT ADVANCEMENTS IN SALIVARY GLAND IMAGING – A REVIEW

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ABSTRACT

Salivary gland imaging plays a vital role in the diagnosis and management of various glandular disorders, including sialolithiasis, inflammatory diseases, and neoplastic conditions. A range of imaging modalities, such as conventional radiography, ultrasonography, computed tomography (CT), magnetic resonance imaging (MRI), and nuclear medicine techniques, are used to evaluate glandular structure, ductal anatomy, and functional status. Ultrasonography is commonly used as the first-line modality, while CT and MRI provide detailed assessment of deep lesions and tumor spread. Emerging technologies, including MR sialography, contrast- enhanced ultrasound, artificial intelligence, and hybrid imaging, are enhancing diagnostic precision and facilitating minimally invasive treatment planning for improved patient outcomes.

KEYWORDS: *Salivary gland imaging; Ultrasonography; Magnetic resonance imaging; Sialolithiasis; Sialoendoscopy*

INTRODUCTION

Salivary glands play a fundamental role in maintaining oral and digestive health by producing saliva, which is essential for lubrication, initial digestion, antimicrobial defense, and protection of oral tissues. The salivary gland system consists of three major glands the parotid, submandibular, and sublingual glands as well as numerous minor salivary glands distributed throughout the oral mucosa. Saliva is initially secreted as an isotonic fluid by acinar cells containing enzymes such as amylase and mucins, and is subsequently modified within the ductal system through electrolyte exchange, resulting in hypotonic saliva. The secretion process is regulated by autonomic innervation, where parasympathetic stimulation primarily promotes fluid secretion via acetylcholine, while sympathetic stimulation facilitates the release of protein-rich components through noradrenaline-mediated pathways.[1,2]

The selection of an appropriate imaging modality depends on the clinical presentation and the suspected underlying pathology. Ultrasonography is widely regarded as the first-line imaging technique because it is non-invasive, readily available, free of ionizing radiation, and capable of providing real-time assessment of glandular structure, vascularity, and guidance for fine needle aspiration or biopsy.[3] Computed tomography (CT), particularly non-contrast CT, is highly effective for detecting salivary calculi, including small or multiple stones, and provides detailed anatomical information. Magnetic resonance imaging (MRI), including magnetic resonance sialography, offers superior soft tissue contrast and allows detailed evaluation of glandular parenchyma, ductal structures, and perineural tumor spread without the need for invasive duct cannulation. Conventional sialography remains valuable for detailed visualization of the ductal system and identification of ductal strictures or obstructions, although its use has decreased with the development of non-invasive imaging modalities. Nuclear medicine techniques are useful for functional assessment of salivary glands, particularly in systemic autoimmune disorders such as Sjögren’s syndrome.

Advanced techniques such as diffusion-weighted imaging (DWI) and dynamic contrast- enhanced MRI (DCE-MRI) further improve the ability to distinguish benign from malignant tumors by analyzing enhancement patterns and apparent diffusion coefficient values[3]. In recent years, technological advancements have significantly enhanced the diagnostic capabilities of salivary gland imaging. Non-invasive imaging modalities such as high-resolution ultrasonography and MRI have improved the evaluation of glandular pathology, while minimally invasive procedures like sialoendoscopy have emerged as valuable tools for both diagnosis and treatment of ductal disorders, particularly in the management of salivary stones and strictures.[4,5] This article gives an overview on Imaging Modalities of Salivary glands.

Anatomy of Salivary Glands Relevant to Imaging

The parotid gland is the largest salivary gland and is situated anterior to the ear and the sternocleidomastoid muscle, extending around the ramus of the mandible. It is anatomically divided into superficial and deep lobes by the facial nerve and retromandibular vein, with the superficial lobe being larger and more accessible on imaging studies. On ultrasonography, the parotid gland typically appears hyperechoic with a

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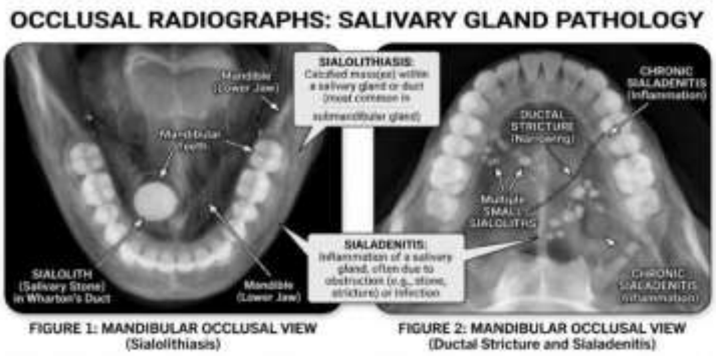
homogeneous echotexture, while on CT and MRI it demonstrates density or signal intensity comparable to surrounding soft tissue and fat.[6] The submandibular gland is located within the submandibular triangle beneath the mylohyoid muscle and has an inverted pyramidal configuration composed of mixed serous and mucous acini. It consists of a superficial lobe that lies medial to the body of the mandible and a deep lobe that extends superiorly around the posterior margin of the mylohyoid muscle, with the posterior belly of the digastric muscle serving as an important anatomical landmark during imaging. The sublingual gland, the smallest of the major salivary glands, is located in the anterior floor of the mouth between the oral mucosa and the mylohyoid muscle. It has an almond-shaped configuration and lacks a well-defined capsule, draining through multiple small ducts known as the ducts of Rivinus, which either empty directly into the oral cavity or join the submandibular duct.[7]

On imaging studies, the sublingual gland typically appears slightly hypoechoic relative to adjacent muscles. In addition to the major glands, the oral cavity contains approximately 600 to 1000 minor salivary glands, each measuring about 1–2 mm in diameter and embedded within the lamina propria of the oral mucosa lining the lips, cheeks, palate, and tongue. These glands predominantly produce mucous secretions and are generally not individually visible on routine imaging unless they become enlarged due to pathological processes, in which case they may appear as small submucosal nodules on ultrasound or MRI[8]. The ductal system of the salivary glands is another important component assessed during imaging. The parotid duct, or Stensen's duct, measures approximately 8 cm in length and originates from the anterior border of the parotid gland, passing over the masseter muscle before piercing the buccinator muscle and opening into the oral cavity opposite the maxillary second molar. On axial CT or MRI images, this duct can often be identified along the course of the masseter muscle and may appear dilated in cases of ductal obstruction.[9]

The submandibular duct, also known as Wharton's duct, is the longest major salivary duct at approximately 5 cm in length and follows a curved course from the deep portion of the submandibular gland, looping around the lingual nerve before opening at the sublingual papilla near the lingual frenulum. Because of its long and tortuous pathway, it is particularly susceptible to the formation of salivary calculi, and when dilated it may appear as a hypoechoic tubular structure on ultrasonography. The Bartholin duct represents the major excretory duct of the sublingual gland and may either merge with the submandibular duct or drain independently into the oral cavity; although it is rarely visualized separately on conventional imaging, MR sialography can demonstrate the branching pattern of these small ducts as fluid-filled channels. Several anatomical landmarks assist radiologists and clinicians in interpreting salivary gland imaging accurately.[10] These include the facial nerve, which, although not directly visible on most imaging studies, can be inferred based on the relationship between the deep lobe of the parotid gland and the retromandibular vein; the angle and ramus of the mandible, which form important lateral boundaries for the parotid and submandibular glands; the mylohyoid muscle, which separates the superficial and deep components of the submandibular gland; and the lingual nerve, which lies medial to the submandibular gland and duct.[11] Ultrasonography typically utilizes high-frequency probes to evaluate glandular echotexture and vascularity, while CT and MRI rely on the identification of fat planes, vascular structures such as branches of the external carotid artery, and adjacent bony landmarks including the skull base to determine glandular boundaries and assess tumor spread or infiltration into surrounding tissues.[12]

Imaging Modalities in Salivary Gland Evaluation Conventional Radiography in Salivary Gland Imaging

Figure 1



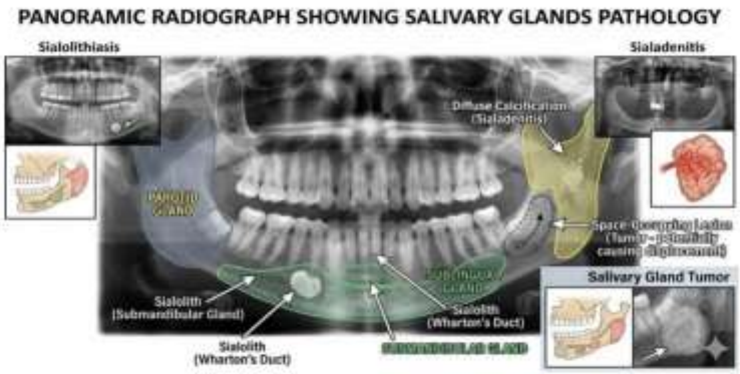


Figure 2

Conventional radiography represents one of the earliest and most accessible methods used in the initial evaluation of salivary gland disorders, particularly for the detection of calcified salivary stones. Techniques such as occlusal radiography and panoramic radiography are commonly employed to identify radiopaque sialoliths and assess gross structural abnormalities of the salivary glands.[13] Occlusal radiographs are especially useful for examining the submandibular and sublingual regions.[Figure 1] In this technique, the radiographic film or sensor is placed against the floor of the mouth while the X-ray beam is directed upward, allowing visualization of the course of Wharton's duct and the anterior floor of the oral cavity. This view is particularly effective in detecting stones located within the submandibular duct, which is the most frequent site of sialolith formation. Upper occlusal views may also be used to evaluate the sublingual area, although visualization of the parotid gland is generally limited due to superimposition of surrounding anatomical structures.[14] Panoramic radiography, or orthopantomography (OPG), provides a broader overview of the maxillofacial region by capturing both sides of the jaws and associated structures in a single image. This technique can reveal the anatomical region of the submandibular gland within the submandibular triangle as well as the approximate location of the parotid gland adjacent to the mandibular ramus. Panoramic images are helpful in detecting larger salivary stones, gland enlargement, or calcified masses, though their diagnostic accuracy may be affected by magnification, distortion, and the inherent limitations of two-dimensional imaging.[15] [Figure 2]

The primary clinical indication for conventional radiography in salivary gland evaluation is the detection of radiopaque sialoliths, particularly those associated with the submandibular gland, which accounts for approximately 80–90% of salivary calculi cases. It may also assist in confirming ductal obstruction in patients presenting with acute glandular swelling or pain, and can occasionally identify foreign bodies or calcified lesions within the glandular region before further imaging investigations are undertaken.[16] Conventional radiography offers several advantages, including its widespread availability in dental clinics, minimal equipment requirements, relatively low radiation exposure typically ranging from approximately 0.01 to 0.03 mSv for occlusal or panoramic examinations and low cost, making it a convenient option for rapid outpatient assessment.[17] Additionally, the procedure is quick to perform, often requiring only a few seconds to obtain diagnostic images. However, despite these benefits, conventional radiography has several notable limitations. It is unable to detect radiolucent salivary stones, which account for roughly 10–20% of cases and are composed primarily of organic or proteinaceous material. Furthermore, the superimposition of anatomical structures can obscure small lesions, and the lack of soft tissue contrast prevents accurate evaluation of inflammatory conditions, tumors, or ductal abnormalities. The two-dimensional nature of these radiographs also restricts the ability to determine lesion depth, vascular involvement, or detailed ductal anatomy.[18]

Sialography in Salivary Gland Imaging

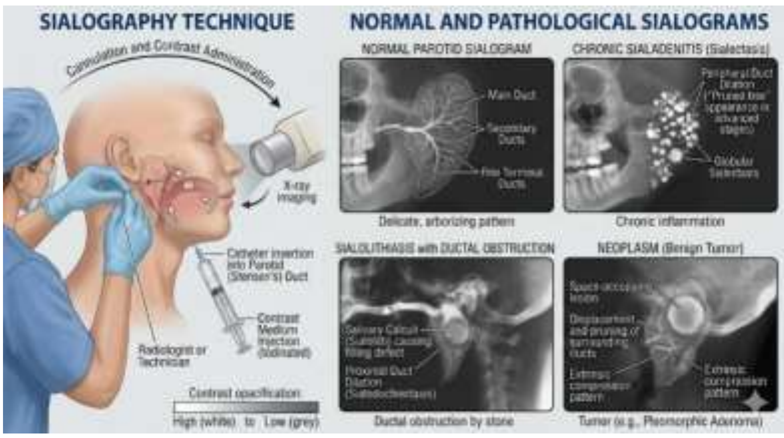


Figure 3

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Sialography is a specialized imaging technique used to evaluate the ductal system of the salivary glands by introducing a radiopaque contrast medium directly into the salivary ducts, allowing visualization of ductal anatomy and associated pathological changes under fluoroscopic guidance.[19] The fundamental principle of sialography involves the careful cannulation of the ductal orifice such as Stensen's duct of the parotid gland, Wharton's duct of the submandibular gland, or Bartholin's duct associated with the sublingual gland followed by the slow injection of a water-soluble, non-ionic, low-osmolar contrast medium, commonly agents such as iohexol. Prior to injection, the ductal opening is identified, stimulated, and dried to facilitate cannulation. [figure 3] Typically, approximately 0.5 to 1.5 mL of contrast medium is introduced until the ductal system and acinar structures are adequately filled.[20]

Fluoroscopy or sequential radiographic imaging is then used to capture the filling phase of the gland, demonstrating the branching pattern of ducts and any structural abnormalities. After imaging, salivary secretion is stimulated, often with lemon juice or other sialogogues, to promote evacuation of the contrast material from the gland. Sialography can be performed using two main techniques: conventional sialography and digital subtraction sialography. Conventional sialography utilizes fluoroscopic imaging combined with plain radiographs taken during and after contrast injection, providing static images of the ductal tree and allowing identification of filling defects, dilatations, or obstructions. While this method is relatively simple and still useful in settings with limited resources, it may be affected by motion artifacts and overlapping anatomical structures.[20] Digital subtraction sialography, on the other hand, involves computerized image processing in which a pre-contrast "mask" image is subtracted from images obtained after contrast injection. This technique enhances the visualization of subtle ductal abnormalities such as strictures, small calculi, or mild dilatations, and often requires smaller volumes of contrast medium. It also improves the visualization of secondary and tertiary duct branches and is particularly helpful when planning interventional procedures such as sialoendoscopy.[21] Clinically, sialography is primarily indicated in cases of suspected ductal obstruction caused by salivary stones or strictures, especially when patients present with recurrent glandular swelling or pain associated with meals. It is also valuable in the evaluation of chronic inflammatory conditions such as chronic sialadenitis or sialectasia, where it helps delineate ductal dilatation, irregularities, or fistulous tracts. Additionally, the technique may be used prior to minimally invasive procedures to assess the morphology and patency of the ductal system.[22]

However, sialography has several contraindications, including acute bacterial sialadenitis, where injection of contrast may worsen infection or cause ductal rupture, as well as in patients with known hypersensitivity to iodinated contrast agents or conditions such as uncontrolled hyperthyroidism. It is also avoided in situations involving recent ductal trauma or severe trismus that prevents proper cannulation of the ductal opening. Characteristic radiographic patterns observed during sialography assist in interpreting glandular structure and pathology. In the normal parotid gland, the ductal system often displays an "apple tree" appearance, in which the main duct branches into progressively smaller ducts terminating in rounded acinar clusters that resemble apples on the branches of a tree.[23] In contrast, the submandibular and sublingual ductal systems may demonstrate a "sausage-link" pattern, characterized by smooth, bead-like dilatations along the duct, reflecting normal physiological variations in duct caliber. The peripheral acinar structures appear as small globular fillings during the contrast phase. These distinctive imaging patterns help clinicians distinguish normal glandular architecture from pathological alterations such as strictures, obstruction, or inflammatory damage within the salivary ductal system.[24]

Ultrasonography in Salivary Gland Imaging

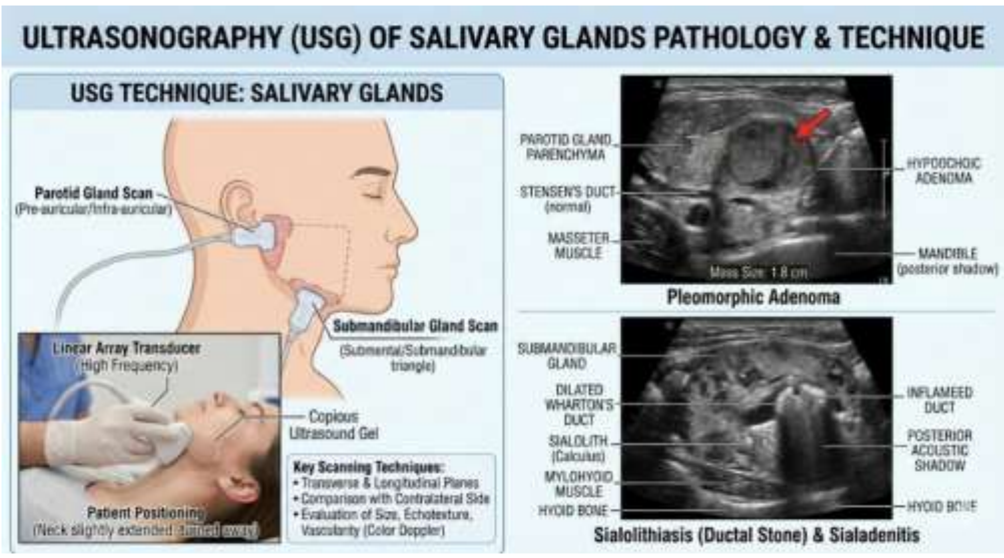

Figure 4

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Ultrasonography (USG) is widely regarded as the first-line imaging modality for the evaluation of salivary gland disorders due to its non-invasive nature, accessibility, and ability to provide real-time visualization of glandular structures. This technique utilizes high-frequency sound waves, typically ranging from 7 to 18 MHz, generated by linear or hockey-stick transducers to produce detailed images of the salivary glands and surrounding tissues. When these sound waves encounter tissue interfaces, they are reflected back to the probe as echoes, which are then processed to create B-mode grayscale images that depict the size, shape, and internal echotexture of the glands. In addition to structural assessment, Doppler techniques such as color Doppler and power Doppler can be used to evaluate vascular flow within the glandular tissue, helping to identify inflammatory changes or tumor vascularity. [Figure 4] During the examination, a linear probe is applied over the region of interest with coupling gel, and the gland is scanned in both axial and longitudinal planes to assess its dimensions, internal architecture, and the presence of focal lesions.[23,24]

Characteristic artifacts, such as acoustic shadowing, may also be observed, particularly in cases of salivary calculi where dense stones block the transmission of ultrasound waves. Clinically, ultrasonography is indicated as an initial diagnostic tool for patients presenting with salivary gland swelling, pain, or palpable masses, particularly in the parotid and submandibular glands. It is highly effective in detecting sialolithiasis, where stones typically appear as hyperechoic structures producing posterior acoustic shadowing, most commonly within the submandibular gland and its duct.[25]

Ultrasonography is also useful for differentiating solid from cystic lesions, identifying tumors, and evaluating vascular patterns that may suggest benign or malignant pathology. In inflammatory conditions such as acute or chronic sialadenitis, the glands may appear enlarged and hypoechoic with heterogeneous echotexture, often accompanied by increased vascularity on Doppler imaging, while abscesses may present as localized fluid collections.[26]

One of the major advantages of ultrasonography is that it does not involve ionizing radiation or the use of contrast agents, making it safe for repeated use and suitable for patients of all age groups, including pregnant women. Furthermore, the technique allows dynamic, real-time scanning, enabling clinicians to observe glandular movement, guide needle aspiration or biopsy procedures, and obtain multiplanar views of the glandular region. Ultrasonography is also relatively cost-effective, widely available, and can often be performed at the bedside or in outpatient settings, offering high spatial resolution for superficial structures. Despite these benefits, ultrasonography has certain limitations. The quality and interpretation of images are highly operator-dependent, requiring significant experience to accurately identify subtle abnormalities.[27] Visualization of deeper anatomical regions, such as the deep lobe of the parotid gland or structures located behind the mandible, may be limited due to interference from bone or air-containing tissues. Additionally, factors such as patient obesity or movement during the examination can degrade image quality, and small calculi located deep within the ductal system may occasionally be missed.[28]

Computed Tomography in Salivary Gland Imaging

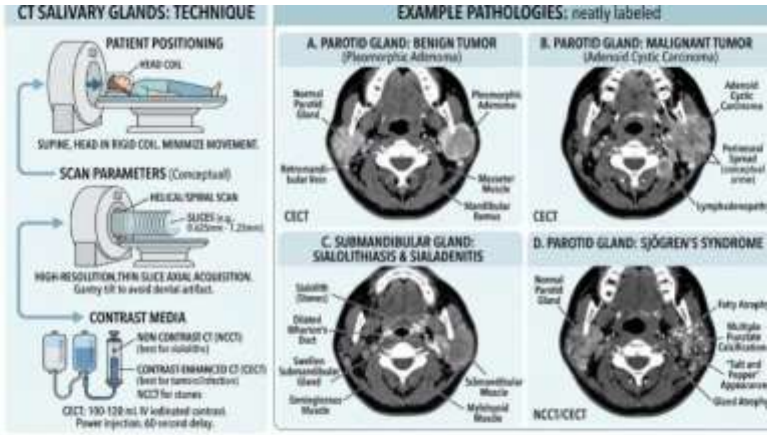

Figure 5

Computed tomography (CT) is an advanced imaging modality that provides detailed cross- sectional visualization of salivary glands through the use of X-rays and computerized image reconstruction. This technique is particularly valuable for evaluating complex salivary gland conditions, especially when ultrasonography is inconclusive or when deeper anatomical structures must be assessed. CT imaging offers excellent visualization of both soft tissue and surrounding osseous structures, making it highly effective in detecting calcifications and evaluating the anatomical relationships of salivary glands with adjacent tissues. [Figure 5] It is commonly indicated in the assessment of salivary gland tumors, where it helps determine lesion size, margins, local invasion, and regional lymph node involvement, particularly in masses arising from the parotid gland.[29]

CT is also useful in identifying lesions involving the deep lobe of the parotid gland or retromandibular region, which are often difficult to visualize using ultrasound due to overlying bone structures. In cases of infection, CT imaging can detect complications such as abscess formation, cellulitis, phlegmon, or even osteomyelitis involving adjacent bones. Additionally, CT is considered one of the most reliable methods for detecting salivary calculi, as even very small stones or intraglandular calcifications can be identified as high-density foci within the ductal system or glandular tissue. The advantages of CT include

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its excellent spatial resolution, often reaching sub-millimeter levels, which allows precise localization of lesions and accurate evaluation through multiplanar image reconstruction. It is particularly effective in identifying calcifications and differentiating salivary stones from other calcified structures such as phleboliths or dystrophic calcifications.[30]

Furthermore, CT imaging is relatively fast and widely available in most healthcare settings, and it generally performs better than MRI in managing artifacts produced by dental restorations or metallic hardware. Despite these benefits, CT also has certain limitations. One of the primary concerns is exposure to ionizing radiation, which may range from approximately 5 to 20 mSv depending on the scanning protocol, making repeated examinations less desirable due to cumulative radiation risk. Additionally, CT provides less soft tissue contrast compared with magnetic resonance imaging, which limits its ability to accurately evaluate subtle soft tissue abnormalities such as perineural tumor spread, mild inflammatory edema, or small cystic lesions. The use of iodinated contrast agents in CT imaging may also pose risks, including allergic reactions or contrast-induced nephropathy in susceptible patients. Another limitation is the potential for beam-hardening artifacts caused by metallic dental restorations or implants, which can degrade image quality in the maxillofacial region.[29,30]

Magnetic Resonance Imaging in Salivary Gland Imaging

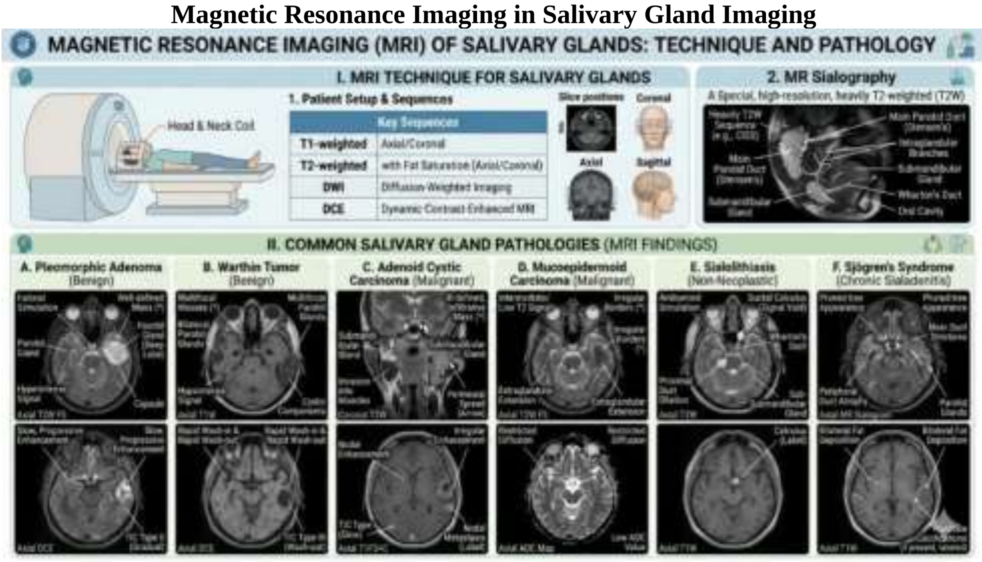

Figure 6

Magnetic resonance imaging (MRI) is a highly advanced imaging modality that plays a crucial role in the evaluation of salivary gland disorders due to its excellent soft tissue contrast and multiplanar imaging capability. Unlike techniques that rely on ionizing radiation, MRI uses strong magnetic fields and radiofrequency pulses to generate detailed images of anatomical structures, making it particularly valuable for assessing complex salivary gland pathologies that may not be clearly visualized on ultrasound or conventional radiography.[29] MRI is especially useful in the evaluation of salivary gland tumors, where it helps determine lesion boundaries, internal characteristics, local invasion, and the presence of recurrent disease, as commonly seen in tumors such as pleomorphic adenoma. [Figure 6] It is also the preferred imaging technique for detecting perineural tumor spread, particularly in malignancies such as adenoid cystic carcinoma, where tumor cells may track along cranial nerves toward the skull base. In addition, MRI provides excellent differentiation of soft tissues, allowing clinicians to distinguish between cystic lesions, inflammatory edema, fibrosis, abscesses, and solid masses with a high degree of accuracy.[30] One of the major advantages of MRI is its superior soft tissue contrast resolution, which enables the visualization of subtle pathological changes such as tissue edema, perineural involvement, and internal tumor heterogeneity that may not be evident on other imaging modalities. Furthermore, the absence of ionizing radiation makes MRI a safe option for repeated examinations, particularly in younger patients or in long-term follow-up of salivary gland tumors.[31]

The technique also allows imaging in multiple planes axial, sagittal, and coronal facilitating comprehensive assessment of complex anatomical regions such as the skull base, deep lobe of the parotid gland, and the floor of the mouth. Several MRI sequences contribute to the detailed evaluation of salivary gland structures. T1-weighted imaging provides a baseline anatomical overview in which glandular tissue typically appears with intermediate signal intensity, while tumors often appear relatively hypointense and cystic lesions appear darker. When contrast agents such as gadolinium are administered, areas of vascularity and tumor enhancement can be evaluated, with benign tumors generally showing slower and more uniform enhancement compared to the rapid and heterogeneous enhancement often seen in malignant lesions. T2- weighted imaging is particularly sensitive to fluid content and inflammatory changes, with edema, cysts, and dilated ducts appearing hyperintense, whereas some high-grade malignant tumors may demonstrate relatively lower T2 signal intensity due to increased cellularity.[31]

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Nuclear Medicine Imaging in Salivary Gland Evaluation

Nuclear medicine imaging, particularly salivary gland scintigraphy, plays an important role in assessing the functional status of the salivary glands and complements anatomical imaging techniques such as ultrasonography, CT, and MRI. This technique primarily utilizes the radiotracer Technetium-99m pertechnetate (Tc-99m), which enables dynamic evaluation of salivary gland uptake and excretory activity. After intravenous administration of approximately 185–370 MBq of Tc-99m pertechnetate, the tracer is actively taken up by salivary acinar cells through the sodium-iodide symporter mechanism, similar to the way iodide is transported in glandular tissues.[32] The tracer accumulates within the salivary glands and is subsequently secreted into the ductal system. During the procedure, dynamic imaging is performed over a period of approximately 20–40 minutes, allowing continuous monitoring of tracer uptake, concentration, and excretion. Stimulation of salivary secretion is usually achieved using lemon juice or other sialogogues, which promotes the release of the tracer into the ducts and oral cavity. The resulting data generate time–activity curves that provide quantitative measurements such as uptake ratios between the parotid and submandibular glands and the ejection fraction, representing the percentage of tracer expelled after stimulation. Under normal conditions, the parotid glands account for roughly 60% of total tracer uptake, while the submandibular glands contribute about 40%, and more than 50% of the accumulated tracer is typically expelled following stimulation.[33] Because Tc-99m pertechnetate behaves similarly to chloride ions in glandular tissue, its distribution reflects gland viability and secretory capacity. Abnormal patterns may include reduced tracer uptake, which may indicate glandular atrophy, inflammation, or damage; diminished excretion following stimulation, suggesting ductal obstruction or autoimmune destruction such as that seen in Sjögren's syndrome; or focal areas of increased tracer concentration, sometimes referred to as "hot spots," which may be associated with certain tumors such as Warthin's tumor.[34]

Clinically, salivary gland scintigraphy is primarily indicated for the functional assessment of glandular activity in conditions affecting salivary secretion. It is particularly valuable in evaluating unilateral or bilateral gland dysfunction, such as obstruction, post-radiation xerostomia, trauma-related gland injury, or other conditions that impair salivary secretion. The technique also plays a significant role in the diagnosis of Sjögren's syndrome, where characteristic findings include markedly reduced tracer uptake in both parotid and submandibular glands and minimal or absent excretion following stimulation, reflecting progressive destruction of glandular tissue. Scintigraphy can assist in grading disease severity and may be particularly useful when serological tests or minor salivary gland biopsies provide inconclusive results. Additionally, nuclear imaging can help identify functional abnormalities associated with salivary gland tumors, such as the increased uptake seen in Warthin's tumors or reduced activity associated with pleomorphic adenomas. It may also be used to assess gland viability in special clinical scenarios, including evaluation of pediatric xerostomia, post- transplant gland function, or before salivary gland autotransplantation procedures.

Cone Beam Computed Tomography and Sialoendoscopy in Salivary Gland Imaging

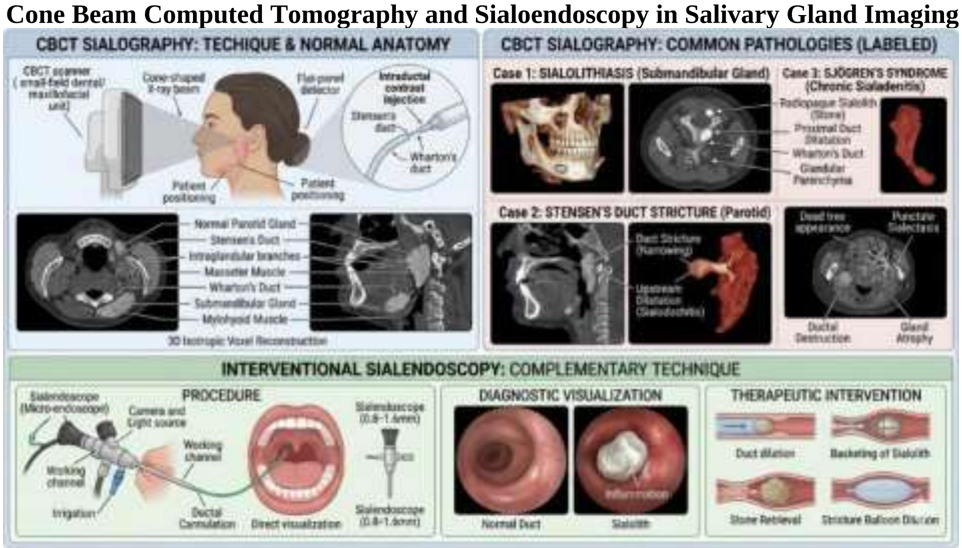

Figure 7

Cone Beam Computed Tomography (CBCT) imaging technique utilizes a cone-shaped X-ray beam and a rotating detector to capture volumetric data, which are reconstructed into detailed multiplanar and 3D images of the maxillofacial region. CBCT is particularly valuable in the detection of salivary gland calculi, demonstrating high sensitivity reported to be approximately 94% for identifying stones located within the submandibular and parotid glands, including small, proximal, or intraglandular calculi that may be difficult to visualize with conventional radiography or ultrasound. [figure 7] In addition to stone detection, CBCT can be used for detailed evaluation of the salivary ductal system through contrast-enhanced techniques such as sialo-CBCT, which allow mapping of ductal strictures, dilatations, and branching patterns of ducts up to higher-order divisions.[35] This capability makes CBCT particularly useful in pre- procedural planning, as the three-dimensional anatomical information obtained can guide interventions such as sialoendoscopy, salivary stone retrieval, or surgical excision of glandular lesions. One of the major advantages of CBCT is its relatively low radiation dose, typically ranging from approximately 0.1 to 0.5 mSv, which is significantly lower than that of conventional CT scans that may

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expose patients to doses between 5 and 20 mSv. Additionally, CBCT provides excellent spatial resolution with isotropic voxel sizes ranging from about 0.1 to 0.4 mm, allowing precise visualization of intraglandular structures and calcifications. Complementing these imaging techniques, sialoendoscopy has gained increasing importance as both a diagnostic and therapeutic tool for salivary gland disorders. This minimally invasive endoscopic procedure involves the insertion of a very small endoscope, typically measuring about 1.3 to 1.6 mm in diameter, into the salivary duct through cannulation of the ductal orifice.[36] Sialoendoscopy enables direct visualization of the ductal system, allowing clinicians to confirm imaging findings such as the presence of salivary stones, ductal strictures, or inflammatory changes. In addition to its diagnostic value, the technique also provides therapeutic capabilities, including the removal of salivary calculi using micro-baskets, forceps, or laser fragmentation, as well as dilation of strictures within the ductal system.[37]

Recent Advances in Salivary Gland Imaging

Advances in imaging now integrate sophisticated MRI techniques, contrast-enhanced ultrasonography, artificial intelligence–based analysis, and hybrid imaging methods to provide both anatomical and functional information. One notable development is MR sialography, a non-invasive imaging technique that uses heavily T2-weighted sequences such as three- dimensional FASTE or constructive interference in steady state (CISS) to visualize the salivary ductal system. In this technique, naturally present saliva acts as an intrinsic contrast medium, allowing visualization of major and minor ducts up to tertiary branches without the need for ductal cannulation or contrast injection. This approach can effectively identify ductal strictures, sialoliths, and ductal dilatations, while advanced image reconstruction techniques can generate virtual endoscopic three-dimensional models that simulate intraductal views and assist in planning procedures such as sialoendoscopy. Another important innovation is contrast-enhanced ultrasonography (CEUS), which utilizes microbubble contrast agents administered either intravenously or intraductally to improve visualization of vascularity and parenchymal perfusion within salivary glands. CEUS allows real-time assessment of glandular blood flow and enhancement patterns, helping differentiate viable glandular tissue from atrophic or fibrotic regions and improving diagnostic accuracy in cases of ductal obstruction or inflammatory disease.[19] Diffusion-weighted MRI (DWI) represents another valuable advancement, providing functional information about tissue cellularity by measuring the diffusion of water molecules within tissues. The derived apparent diffusion coefficient (ADC) values help differentiate benign from malignant lesions, with malignant tumors typically demonstrating lower ADC values due to higher cellular density, while benign lesions or cystic structures exhibit higher ADC values. DWI can also assist in tumor grading, treatment response monitoring, and detection of recurrence. In addition, emerging techniques such as virtual MR elastography derived from diffusion imaging can estimate tissue stiffness, which may aid in distinguishing certain tumor types such as Warthin's tumors that demonstrate relatively higher stiffness.[38]

The integration of artificial intelligence (AI) and machine learning into imaging analysis is also transforming the field of salivary gland diagnostics. AI algorithms are increasingly being used to analyze histopathological whole slide images and radiological datasets, enabling automated classification, subtyping, and grading of salivary gland tumors with high diagnostic accuracy. In the future, AI-assisted systems may also analyze ultrasound, CT, and MRI scans to identify subtle imaging patterns, detect early malignancies, and predict treatment outcomes such as the response of sialolithiasis to minimally invasive procedures. Advances in three-dimensional imaging technologies have further enhanced diagnostic capabilities. Techniques such as CBCT- sialography provide high-resolution three-dimensional visualization of the salivary ductal system, facilitating accurate localization of stones and strictures.[39] Hybrid imaging modalities, including positron emission tomography combined with MRI (PET-MRI), allow simultaneous evaluation of anatomical, functional, and metabolic information, which is particularly useful in staging salivary gland malignancies and detecting metastatic disease. Additionally, molecular imaging approaches that target specific cellular receptors such as PSMA-based PET imaging are being explored for identifying metastatic lesions and improving oncologic assessment. Emerging nanotechnology-based diagnostic tools, including nanophotonic biosensors, may also enable point-of-care detection of salivary gland tumors through molecular analysis of saliva or tissue samples.[40]

Conclusion

Salivary gland imaging plays a crucial role in the accurate diagnosis and management of a wide range of glandular disorders, including obstructive, inflammatory, and neoplastic conditions. Conventional techniques such as radiography and sialography remain useful, while modern modalities like ultrasonography, CT, and MRI provide detailed structural and functional evaluation. Emerging technologies, including advanced MRI sequences, contrast-enhanced ultrasound, and artificial intelligence–assisted analysis, are further improving diagnostic accuracy and clinical decision-making. Together, these advancements support earlier detection, minimally invasive treatment planning, and more personalized management of salivary gland diseases.

Abbreviations

1. USG- Ultrasonography
2. CT- Computed Tomography
3. MRI- Magnetic Resonance Imaging
4. CBCT- Cone Beam Computed Tomography
5. DWI- Diffusion Weighted Imaging
6. DCE-MRI- Dynamic Contrast Enhanced Magnetic Resonance Imaging
7. MR- Magnetic Resonance
8. CEUS- Contrast Enhanced Ultrasonography
9. AI- Artificial Intelligence
10. OPG- Orthopantomogram/ Panoramic Radiography
11. Tc-99m- Technetium-99m
12. MBq- Megabecquerel
13. ADC- Apparent Diffusion Coefficient
14. FASTE- Fast Spin Echo Technique
15. CISS- Constructive Interference in Steady State
16. PET- Positron Emission Tomography
17. US- Ultrasound

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18. B-mode- Brightness Mode Ultrasound
19. mSv- Millisievert
20. MHz- Megahertz

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