

Efficiency of hyphenated analytical techniques in detecting chemical and histological problems or abnormalities in dental diseases

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ABSTRACT

This study explores the role of hyphenated and hybrid techniques in modern dental diagnostics by integrating chemical analysis, medical imaging, and artificial intelligence to achieve early and accurate detection of dental diseases. It highlights the limitations of conventional visual examination and radiography, which often fail to identify biochemical and histological changes in their early stages, leading to delayed treatment and poor outcomes. By combining AI-based imaging—especially convolutional neural networks applied to dental radiographs—with advanced analytical methods such as GC-MS, FIA-UV-Vis, and RP-HPLC, these approaches enable the detection of subtle biomarkers in saliva, metabolic changes, and structural abnormalities that are otherwise overlooked. The research demonstrates that such integrated systems enhance diagnostic precision, reduce human error, accelerate clinical decision-making, and improve patient care. Ultimately, the study concludes that the combination of AI-assisted imaging and GC-MS offers the most comprehensive and effective framework for early detection and management of oral diseases, and recommends adopting this modern diagnostic model in dental colleges, particularly in Iraq, to advance preventive and therapeutic dentistry.

This work is a narrative review supported by analytical observations of available diagnostic technologies in Iraqi institutions, aiming to propose a modern framework for dental diagnostics.

This study aims to:

- Review the role of AI and hybrid analytical techniques in dental diagnosis.
- Evaluate the efficiency of hyphenated techniques in detecting chemical and histological abnormalities.
- Compare conventional diagnostic methods with hybrid approaches.
- Highlight the potential of these techniques in early detection of oral diseases.

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1. Introduction And Literature review

This section provides a theoretical background on hyphenated and hybrid techniques, explaining their principles, classifications, and advantages. It establishes the scientific foundation required to understand their application in dentistry.

The term "hyphenated methodology" refers to a strategy that combines two different analytical methodologies with the use of a suitable interface. Chromatographic processes are typically used in conjunction with spectroscopic techniques. Using standards or library spectra generated by spectroscopy, the pure or almost pure portions of the chemical components in a mixture were separated, and selective information was used for identification. In 1980, Hirschfeld coined the phrase "hyphenation" to describe the possible combination of two or more instrumental analysis methods in a single run. Hirschfeld (1980). Compared to utilizing a single using an analytical approach, the coupling seeks to offer an detection with lots of information for both identification as well as measurement. Benefits:

1. It is employed for precise and quick analysis
2. The level of automation is higher.
3. Increased throughput of samples.
4. Improved repeatability.
5. Because of its closed system, it aids in lowering contamination.
6. Quantification separation concurrently [20]

1- Techniques with two hyphens. 2. Techniques with three hyphens.

Techniques with two hyphens	Techniques with three hyphens
Liquid chromatography-mass spectrometry (LC-MS)	Liquid chromatography-Atmospheric pressure ionization mass spectrometry (LC-API-MS)
Liquid chromatography – Nuclear magnetic resonance spectroscopy (LC-NMR)	Atmospheric pressure chemical ionization mass spectrometry monitoring system (APCI-MS-)
Liquid chromatography-Infrared spectroscopy (LC-IR)	Electron spray ionization mass spectrometry (ESI-MSMS)
Continuous emission-monitoring system (CE-MS)	Large volume injection gas chromatography mass spectrometry (I-GC-MS)
Gas chromatography-infrared spectroscopy (GC-IR)	Liquid chromatography Electron spray ionization mass spectrometry (LC-ESI-MS)
Gas chromatography-mass spectrometry (GC-MS)	Liquid chromatography mass spectrometry

<p>C-MS) High performance liquid chromatography-photodiodearray Detection (HPLC-DAD) Gas chromatography- Fourier transform infrared spectroscopy (GC-FTIR)</p>	<p>lectron spray ionization (LC-UV-NMR-MS-MS) Liquid chromatography mass spectroscopy Nuclear magnetic resonance mass spectroscopy (LC-NMR-MS) Liquid chromatography photodiode array detection mass spectroscopy (LC-DAD-API-MS) Liquid chromatography Photodiode array detection mass spectroscopy (LC-PDA-MS) Liquid chromatography Nuclear magnetic resonance mass spectroscopy (LC-PDA-NMR-MS SPE-MS)</p>
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1. Clinical Relevance of Dental Diseases

Understanding the biological and clinical nature of dental diseases is essential before discussing diagnostic technologies. This section highlights the most common oral diseases that require early and accurate detection.

1. Dental Diseases

The fact that oral and dental diseases are easily treated in early stages [6], do not minimize that Prevalence of the main oral diseases increasing globally with growing urbanization and changes in living conditions hence the need for rapid effortless diagnostic approaches [7].

1. Dental Caries (Tooth Decay)

Dental caries occurs when plaque forms on the surface of a tooth and converts the free sugars (all sugars added to foods by the manufacturer, cook or consumer, plus sugars naturally present in honey, syrups and fruit juices) contained in foods and drinks into acids that damage the tooth structure over time. A continued high intake of free sugars, inadequate exposure to fluoride and a lack of plaque removal by tooth brushing can lead to caries, pain and sometimes tooth loss and infection Like Figure (1.1) below [8]

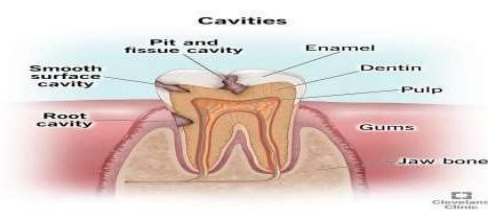
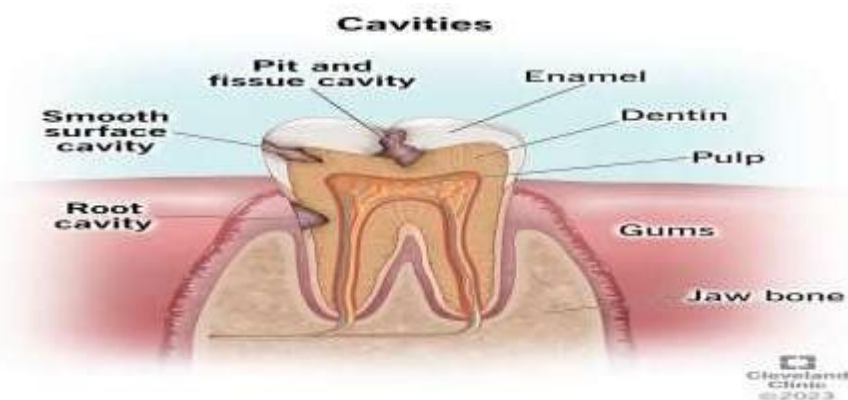


Fig. (1.1) : Dental Caries

The main three types of dental caries (categorized according to the area affected) are summarized as Smooth surface decay that dissolve the surface of the tooth ,pit and fissure decay that affect the chewing surface and the front side of the molar teeth and root decay that manifest the gum regress exposing the root[9] , bacteria, acid, food and saliva mix to form dental plaque combined with the Lack of proper brushing and flossing, facilitate the action



acids dissolving tooth enamel, creating cavities, or holes, in the enamel surface [10]

For individuals with typical genetics or without medical history that predispose dental caries Brushing teeth with a soft-bristled brush and fluoride toothpaste at least twice a day, lower the consumption of starchy foods and drinks, daily flossing, biannual dentist appointments and using dental sealants are considered the ideal prevention measures [12].

1.1.1 Periodontal (Gum) Disease

Periodontal disease affects the periphery that both surround and support the teeth, characterized by a significant inflammatory appearance with the infiltration of PMN and congestion (gingivitis)). the inflammation usually proceed until the inflamed tissue can no longer support the tooth or nourish it. Severe periodontal diseases are estimated to affect around 19% of the global adult population, representing more than 1 billion cases worldwide. The main risk factors for periodontal disease are poor oral hygiene and smoking Like Figure (1.2) below [13].



Fig. (1.2): Periodontal (gum) disease

Periodontal disease present in 4 stages, the first stage known as Gingivitis. Earliest stage of gum disease. It starts with red, puffy gums that may bleed when brushing or flossing. At this stage, there's no bone loss. As a result, gingivitis is totally reversible with proper treatment, the second stage, and mild periodontitis. The bacteria have seeped beneath gums, affecting the supporting bone, gums may pull away from the teeth, creating pockets around them. Plaque and bacteria hide in these pockets, Moderate periodontitis(the third stage) bacteria begin to erode the ligaments, soft tissues and bone that hold teeth in place , pain might be evident at this stage, and for last stage Advanced periodontitis., bone loss continues. Causing teeth to become loose [14].

It was observed that Buildup of dental plaque (due to poor oral hygiene) is the most recorded cause of periodontal disease. Genes play a role in gum disease by changing the way immune system responds to bacteria [15], a side from the causes several risk factors predispose the oral cavity to periodontitis, smoking, stress, autoimmune diseases and genetics are the most common, in most cases gum diseases are preventable with consistent and proper oral hygiene. Some people are more prone to gum disease due to genetics or other health conditions. In these instances frequent cleanings with a dental hygienist is mandatory [16].

Edentulism (Total Tooth Loss)

After a extended period of inflammation and histological changes (summarized by acanthosis of the epithelium with hyaline and mucoid degeneration) the loss of teeth is the final result. Direct sudden injury can be a cause too. The estimated average prevalence of complete tooth loss is almost 7% and 23% among people aged 20 years or older and people aged 60 years or older respectively .Losing teeth can affect aesthetics and function Like Figure (1.3) below [17], there are several risk factors associated with total teeth loss. Many of them are risk factors for periodontal disease, which, in turn, cause tooth loss. [18].



Fig. (1.3): Edentulism (total tooth loss)**Oral Cancer**

Oral cancer is noticed when dysplasia of the epithelium is significant (changes from normal squamous epithelium into atypical hyperchromatic cells) The global incidence of cancers of the lip and oral cavity is estimated to be (377 – 713) new cases and (177 – 757) deaths in 2020. Oral cancer is common in men and in older people, Tobacco, alcohol and areca nut (betel quid) use is the main etiology. In North America and Europe like Figure (1.4) below [19].

**Fig. (1.4) : Oral cancer****Fig. (1.4) : Oral cancer**

Other health problems that initiate the occurrence of oral cancer are epstein-barr virus (EBV), family history of mouth cancers, poor oral hygiene and gum disease, exposure to the sun and chewing the seed of the areca palm tree Like Figure (1.5) below [21]



Fig. (1.5): Oral Cancer

Around 59% of mouth cancers in Australia are caused by smoking. Around 31% are caused by excess alcohol consumption. So quitting smoking and moderating alcohol consumption will significantly reduce your risk of developing mouth cancer, especially those inside the mouth. Cancers of the lip are commonly associated with UV exposure, so it is also important to protect yourself from the sun when the UV is 3 or above [22].

Most mouth and oropharyngeal cancers originates from squamous cells and are called squamous cell carcinoma (SCC). Other types of mouth and oropharyngeal cancers [20]:

2. Foods and Medications That Cause Dental Diseases

Sweet Foods and Soft Drinks

Sugar is one of the primary culprits behind tooth decay. When bacteria in the mouth break down sugar, they produce acids that erode tooth enamel, leading to cavities, Candies and sweets promote bacterial growth, Soft drinks and energy drinks contain high levels of sugar and acid which attack enamel and increase the risk of cavities. Even sugar-free sodas contain acids that weaken tooth structure, Fruit juices: are high in natural sugars and acids Like Figure (1.6) below [23].



Fig. (1.6) : Effects of sugar on teeth

Foods with High Acidity

Acidic foods can wear down the protective enamel layer, causing teeth to be more sensitive and prone to decay. Citrus fruits, which can erode enamel over time, Tomatoes and pickles high acidity can soften enamel, especially when consumed frequently, Vinegar-based foods and Salad dressings, pickles, and certain sauces contain vinegar, which contributes to acid erosion. Like Figure (1.7) below [24].



Fig. (1.7): Erosion caused by acidic foods

Alcoholic drinks: Alcohol dries out the mouth, reducing saliva production, which is essential for neutralizing acids and washing away food particles. This increases the risk of cavities and gum disease like Figure (1.8) below [25].



Fig. (1.8) : The Harmful Effect Of Alcohol On Teeth

- **Coffee and tea:** contain tannins that stain teeth over time. If consumed with added

sugar, they also contribute to tooth decay Like Figure (1.9) below.



Fig. (1.9) : Coffee Stained Of Teeth

Antihistamines and Decongestants

Medications used for allergies and colds, such as diphenhydramine (Benadryl) and pseudoephedrine (Sudafed), reduce saliva production, leading to dry mouth. A lack of saliva allows bacteria and acids to accumulate, increasing the risk of tooth decay and gum disease [26].

Antidepressants and Anxiety Medications

Certain antidepressants (e.g., selective serotonin reuptake inhibitors or SSRIs) and anxiety medications cause dry mouth as a side effect. Chronic dry mouth leads to a higher risk of cavities, gum infections, and bad breath [27]

Blood Pressure Medications

Some medications used to control hypertension, such as calcium channel blockers, can lead to gum overgrowth (gingival hyperplasia), making it easier for plaque and bacteria to accumulate. This increases the likelihood of gum disease if proper oral hygiene is not maintained [28].

Traditional diagnostic tools often fail to detect early biochemical and microscopic changes. Therefore, hybrid and hyphenated techniques offer a promising alternative by combining imaging, chemical analysis, and artificial intelligence.

3. Hybrid Techniques

Hybrid technologies refer to the integration of different technological tools or methods to enhance the effectiveness of treatments, diagnoses, or processes. By combining multiple approaches, hybrid systems offer advantages that individual technologies may lack on their own. For example, in dentistry, using artificial intelligence (AI) with digital radiographs helps detect dental issues more accurately

Orthopantomogram Radiographs

Radiographs, on the other hand, have been used to develop Artificial Intelligence (AI)-based decision support systems that have the potential to enhance and speed the diagnostic processes. This technique started to use in dentistry in 2015. In particular, transfer learning, or the use of a pretrained model with pre-learned weights, has been effective in its utility within dental radiographs.

One important type of radiograph used in dentistry is an Orthopantomogram (OPG). An OPG, sometimes called a panoramic radiograph, provides a comprehensive view of the hard tissues of the oral cavity and surrounding skeletal structures.. Despite the potential presence of artifacts in OPGs, they usually provide a more inclusive diagnosis compared to a clinical examination, often discovering diseases that were unseen in the preceding examination through the model's classification layer. In the hybrid approach, the features are extracted using a deep learning model like Figure (2.1) below [30]



Fig. (2.1): A sample OPG radiograph displaying teeth from the four classes (left to right): (1) impacted, (2) filling, (3) implant, and (4) cavity

Hybrid Approaches For Medical And Non-Medical Applications

Hybrid approaches have shown effectiveness in various applications, outperforming other methods. In the non-medical spectrum, classified violence in videos whereas worked on human action recognition more generally. Classified texture from images. On the medical side, worked on the classification of gastrointestinal disease from wireless capsule endoscopy images, categorized breast cancer from mammogram images, and classified multiocular disease from retinal fundus images. Using only handcrafted features, diagnosed human burns from burn images, and categorized the modality of medical images [31].

Applications Of Ai In Dental Diagnostics

Recently, CNN-based approaches have dominated dental diagnostics. Most works in the literature to classify a minimal number of diseases. The performance for this task vary, with accuracy values reaching up to 99% mainly due to good data quality, simplicity of the task, or advantages of the proposed model. Other studies do not achieve such high accuracy values, mainly due to the detection of challenging types of diseases, due to lacking data quality or quantity, or a combination of both. A detailed summary of the studies involving dental diagnosis can be found in. It is worth mentioning that we found no existing works that utilize the dataset that is used in our work. A detailed overview of the dataset is given in subsection III-A [32].

1.1 Hybrid Approach

The hybrid approach, the main emphasis of our paper, is illustrated. This approach utilizes a pre-trained model for feature extraction and a traditional machine learning algorithm for the final classification. Initially, all annotated teeth are extracted from their respective radiographs using the provided coordinates (i.e., bounding box). These subimages (i.e., the teeth) are then preprocessed and fed into a fine-tuned deep learning model, which extracts the learned features for each image. These features are subsequently used to train a traditional machine learning classifier for the final diagnosis. The general training and testing phases of the hybrid approach are shown with an optional Principal Component Analysis (PCA) step where the deep learned features are reduced before training or testing the machine learning classifier This technique start application in dentistry in 2011 like Figure (2.2) below [33].

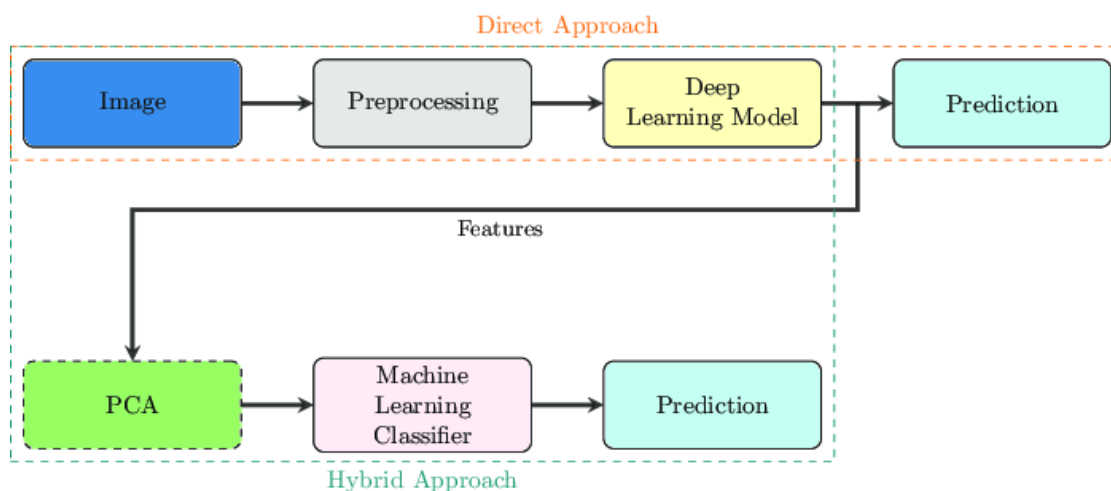


Fig. (2.2): A Comparison Between The Workflow Of The Direct And Hybrid Approaches.

4. Applications of GC-MS in Dentistry

Diagnosis of Oral Diseases Detection of Biomarkers in Saliva:

GC-MS is used to analyze saliva for biochemical markers linked to periodontal diseases, dental caries, and oral infections. Moreover Volatile organic compounds (VOCs) in saliva can indicate metabolic disorders and oral cancer [34].

Analysis of Halitosis (Bad Breath):

The instrument helps identify volatile sulfur compounds (VSCs) like hydrogen sulfide and methyl mercaptan, which are produced by oral bacteria and contribute to bad breath.



This assists in diagnosing conditions such as gingivitis, periodontitis, and systemic diseases that manifest in oral malodor like Figure (2.3) below [35].

Fig. (2.3) : GC-MS

Early Detection of Oral Cancer:

- GC-MS detects carcinogenic compounds such as tobacco-related nitrosamines and oxidative stress markers in saliva and tissue biopsies.
- Helps in monitoring metabolic changes associated with precancerous and malignant lesions GC mass start to use in dentistry according to researches in 2021 [36].

Identification of Microbial Infections:

- Bacterial and fungal infections in the oral cavity produce unique metabolic byproducts.
- GC-MS helps in detecting specific lipopolysaccharides (LPS) and volatile fatty acids that indicate bacterial activity in periodontitis.

1.1.1 Treatment Applications in Dentistry Monitoring Drug Metabolism in Saliva:

- GC-MS is used to study the metabolism and bioavailability of local anesthetics, antibiotics, and analgesics in dental treatments.
- Helps in optimizing personalized drug dosing based on patient-specific metabolic rates [37].

Analysis of Dental Material Biodegradation:

- Composite resins, adhesives, and sealants release small amounts of chemical compounds over time.
- GC-MS detects leachables like Bisphenol A (BPA) from resin-based materials to ensure biocompatibility and patient safety.

Fluoride and Antimicrobial Agent Evaluation:

- The instrument quantifies fluoride levels in oral care products and measures the presence of antimicrobial agents in saliva post-treatment.
- Ensures effective caries prevention and bacterial inhibition.

Post-Treatment Monitoring of Oral Health:

- After periodontal therapy or surgical interventions, GC-MS tracks biochemical changes in oral fluids.
- Assesses healing processes and identifies potential complications like infections or inflammatory responses like Figure (2.4) below [38].

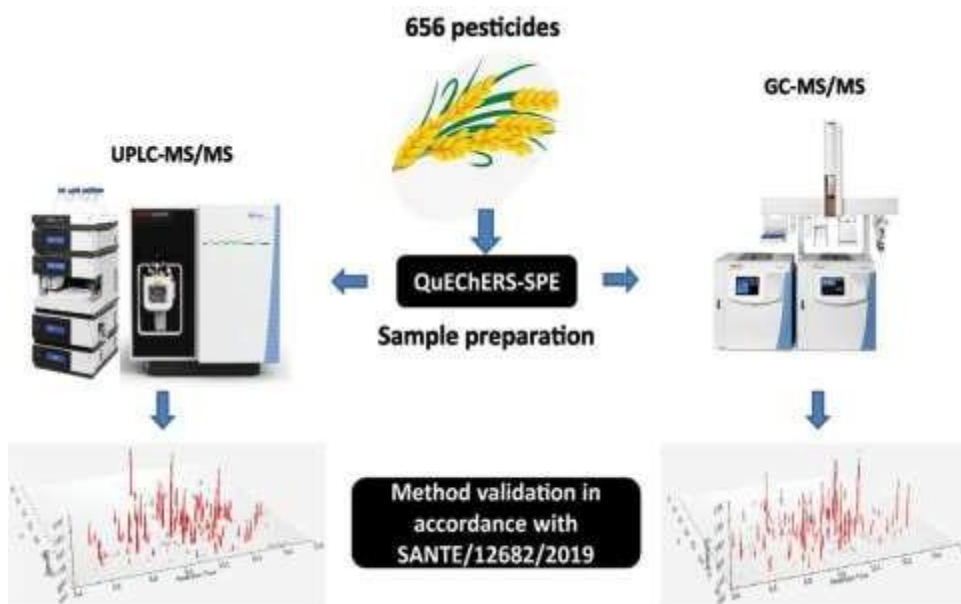


Fig. (2.4) : Graphical Abstract of GC-MS

1.2 Applications of Flow Injection System with UV-Vis Detector in Dentistry

1.2.1 Diagnosis of Dental Diseases With Salivary Biomarker Detection

- The system analyzes salivary proteins, enzymes, and metabolic byproducts associated with oral diseases such as periodontitis, caries, and oral cancer.
- UV-Vis detection enables the quantification of total protein concentration, oxidative stress markers, and inflammatory mediators in saliva [39].

Detection of Fluoride Levels in Saliva and Dental Products:

- Fluoride is essential for preventing dental caries, but excessive exposure can be harmful.
- The UV-Vis detector quantifies fluoride levels in saliva and oral care products, ensuring safe and effective fluoride therapy.

Analysis of Volatile Sulfur Compounds (VSCs) in Halitosis:

- Chronic bad breath (halitosis) is linked to bacterial metabolism in the oral cavity.
- FIA-UV-Vis is used to measure sulfide ions and other volatile sulfur compounds in saliva, helping diagnose bacterial infections responsible for halitosis.

Early Diagnosis of Oral Cancer:

- The system detects nucleic acid modifications, oxidative stress markers, and abnormal protein expressions in saliva and oral tissues, aiding in early detection of oral malignancies. This technique starts to be used in dentistry in year 2023.

1.2.2 Treatment Applications in Dentistry

Monitoring Drug Absorption and Metabolism in Oral Fluids:

- The UV-Vis detector quantifies the concentration of antibiotics, anti-inflammatory drugs, and anesthetics in saliva, ensuring optimal drug dosing for dental treatments.
- Helps in personalized medicine by monitoring drug clearance rates in individual patients [40].

Evaluation of Antimicrobial Agents in Mouth Rinses and Dental Products:

- FIA-UV-Vis is used to assess the efficacy of chlorhexidine, essential oils, and hydrogen peroxide in reducing bacterial load.
- Ensures proper formulation of mouthwashes, gels, and dental coatings for long-lasting antimicrobial effects.

Post-Treatment Monitoring of Periodontal Therapy

- After scaling, root planning, or surgical interventions, FIA-UV-Vis is used to track biochemical

changes in saliva and gingival crevicular fluid (GCF).

- Helps evaluate inflammatory responses, bacterial activity, and tissue healing following Treatment [41].

Application of RP-HPLC in Dentistry for Dental

In dental research 2022, RP-HPLC with a UV detector is gaining significant importance for detecting and analyzing compounds related to Dental diseases. It plays a crucial role in the diagnosis and treatment of various oral health conditions by providing high sensitivity and precision in identifying biomarkers, therapeutic agents, and diagnostic compounds [42].

Detection of Biomarkers for Dental Diseases

RP-HPLC can be used to identify specific biomarkers associated with oral diseases like periodontal disease, oral cancer, and dental caries. For instance, the detection of volatile sulfur compounds (VSCs) produced by bacteria in periodontal disease can be performed using this method. Additionally, the analysis of salivary proteins, peptides, and other metabolites may offer insights into the early stages of oral diseases [43].

Analysis of Therapeutic Agents

RP-HPLC is useful in the analysis of therapeutic agents used in dentistry. These include medications for pain relief, antimicrobials to treat infections, and fluoride preparations. UV detectors can be used to confirm the presence and concentration of these compounds in saliva or in dental products such as mouthwash and paste [44].

Monitoring Drug Delivery

In the case of controlled drug delivery systems (such as those used in the treatment of oral infections), RP-HPLC can be used to monitor drug concentration over time. This ensures that the correct dosage is maintained, which is important for effective treatment [45].

Detection of Contaminants in Dental Materials

Dental materials, such as resins, composites, and adhesives, may contain trace amounts of potentially harmful substances. RP-HPLC can be used to detect these contaminants and ensure the safety and quality of materials used in dental procedures.

Research into Dental Microbiota

RP-HPLC can also be used to study the oral microbiota, which plays an important role in conditions such as periodontitis and oral candidiasis. By analyzing the metabolites produced by

oral bacteria, it becomes possible to gain a better understanding of the microbial composition and its relationship to oral diseases [46].

5. Discussion

We turn to hybrid technologies for the treatment of dental disease because combining different devices and methods improves accuracy, efficiency and patient outcomes. Each technology has its own strengths, and when integrated – such as AI with X-rays or lasers with traditional device they provide more accurate diagnosis, faster treatment, less discomfort and personalized treatment plans. Hybrid approaches reduce human error, save time and costs in the long run, and increase the overall quality of care. GC-Mass

The image shows a Gas Chromatography-Mass Spectrometry system, a highly sophisticated analytical instrument used for identifying and quantifying chemical compounds in complex mixtures. This specific model appears to be a Shimadzu GCMS- QP2010, manufactured by Shimadzu Corporation, a leading Japanese analytical and measuring instruments company. (This image found in Scientific research Authority , center for environmental water and renewable energy research department) like Figure (3.1) below [47].



Fig. (3.1) : GC-Mass device

In this medical research, we explored a new concept by integrating chemistry with dentistry, using hybrid analytical techniques to analyze samples of saliva, food, and medicine, given their impact on dental diseases. We investigated existing techniques used in these analyses in Iraq. We obtained three techniques in three different locations.

Key Components

- Gas Chromatograph (GC): Separates volatile compounds in a sample.
- Mass Spectrometer (MS): Identifies and quantifies the separated compounds by analyzing their mass-to-charge ratio (m/z).
- Autosampler (AOC-20i): Automates the injection of liquid samples for consistent and precise analysis.
- Control Panel and Data Processing System: Operates the instrument and analyzes results like Figure (3.2) below [48].

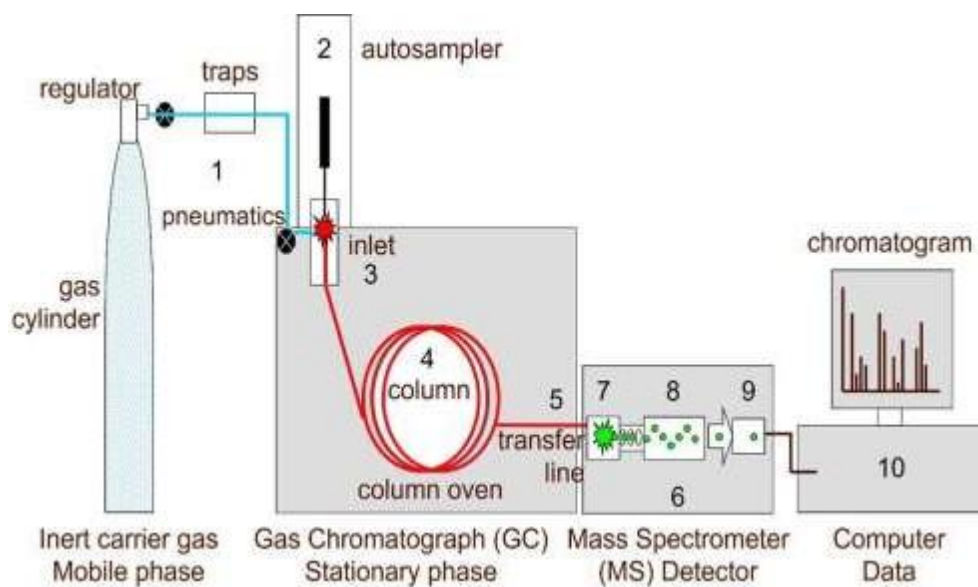


Fig. (3.2) : A simplified diagram of a gas chromatograph–mass spectrometer features and components

3.1.1 Technical Features

- High sensitivity and specificity in detecting volatile and semi-volatile compounds.
- Capable of identifying unknown substances based on mass spectral libraries.
- Used in pharmaceuticals, forensics, environmental analysis, and biomedical research.

3.2 Flow Injection System with UV-Vis Detector in Dentistry

A Flow Injection Analysis (FIA) system with a UV-Visible (UV-Vis) detector is an analytical instrument used for rapid, automated chemical analysis. It is widely used in pharmaceutical,

biomedical, and environmental applications due to its efficiency, precision, and ability to analyze a variety of liquid samples.

The Shimadzu UV mini-1240 digital single beam spectrophotometer was utilized to perform absorbance and spectral measurements in both nFIA and rFIA assays. These measurements were conducted using a movement cell with an internal volume of 50 μ l and a route length of 1 cm (This image found in University of Baghdad college of sciences department of chemistry) like Figure (3.3) below [49] .



Fig. (3.3) : Flow Injection System With Uv-Vis Detector.

3.2.1 Key Components

- Flow Injection System: Automates sample introduction and mixing with reagents before analysis.
- UV-Vis Detector: Measures the absorbance of light at specific wavelengths to quantify analytes.
- Pump System: Ensures continuous flow of samples and reagents through the system.
- Injection Valve: Introduces precise sample volumes into the carrier stream.
- Data Processing System: Records and interprets absorbance data to determine sample composition.

Technical Features

- Rapid and precise sample analysis with minimal reagent consumption.
- High sensitivity for detecting trace amounts of biological and chemical substances.
- Automated operation reduces human error and improves reproducibility.

6. RP-HPLC with UV-Detector

Performed using a device HPLC system, CECIL Company-Britain Reverse Phase High-Performance Liquid Chromatography (RP-HPLC) is a powerful analytical technique widely used in chemistry, biochemistry, and pharmaceutical industries to separate, identify, and quantify components in a mixture. It utilizes a non-polar stationary phase (usually silica-based) and a polar mobile phase (typically a mixture of water and organic solvents). In this method, compounds are separated based on their polarity, with non-polar compounds interacting more strongly with the stationary phase and moving slower than polar compounds. The UV detector is an integral part of RP-HPLC systems. It is used to detect and measure the absorbance of ultraviolet light by the compounds that elute from the chromatographic column. Many organic compounds, including pharmaceuticals, absorb UV light at specific wavelengths, making the UV detector ideal for detecting these substances without the need for complex derivatization (This image found in Tikrit University, College of Chemical Sciences) like Figure (3.4) below [50] .



Fig. (3.4): High performance liquid chromatography with UV-Detector instrument

7. Future Perspectives

Dental diagnostics in the future will rely on increasingly integrated systems that combine image processing, biochemical analysis and artificial intelligence. Implementation of these technologies in dental facilities will increase early detection and reduce the complexity of treatment.

Conclusions

Based on a review of hybrid techniques in dental diagnostics, each method offers distinct benefits and specific uses. However, Convolutional Neural Networks (CNNs) in AI-assisted imaging and Gas Chromatography–Mass Spectrometry (GC-MS) stand out as the most effective and promising approaches.

CNNs in AI imaging show exceptional accuracy in detecting cavities, periodontal disease, and oral cancer. By processing large amounts of image data, AI reduces diagnostic errors and enhances early detection, while also improving efficiency and supporting real-time treatment planning.

GC-MS is highly valuable for identifying saliva biomarkers, detecting volatile sulfur compounds linked to periodontal disease, and analyzing metabolic byproducts related to oral cancer. This allows early molecular-level disease detection, advancing preventive and targeted care.

Although techniques like RP-HPLC and Flow Injection Analysis with UV-Vis detection are useful for specialized biomarker and drug metabolism analysis, the combination of AI-based imaging and GC-MS offers the most comprehensive solution for modern dental diagnostics, ensuring both precision and efficiency in managing oral health.

It is recommended that Iraqi dental colleges adopt hybrid diagnostic platforms by incorporating AI-based radiographic analysis and GC-MS laboratories within their clinical and research infrastructure. This step will enhance early disease detection, improve educational quality, and align dental practice in Iraq with international standards.

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