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SYSTEMATIC REVIEW

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Applications of ultrasound imaging in dental and orofacial region: An updated review

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ABSTRACT

Objective: The purpose of this systematic review is to examine various applications of ultrasonography (US) in the dental and orofacial areas.

Methods: The literature was systematically queried in three prominent databases, namely PubMed, Scopus, and Google Scholar. Only publications that focused on the use of the US in dentistry were chosen, while the remaining articles were used for technical reference purposes.

Results: Out of a total of 300 papers, approximately 70 acceptable studies were ultimately included, which reported the use of the US in the dental and orofacial region. The remaining articles were referred to for technical elements of the US. The publications were thoroughly examined, and comprehensive data regarding the intraoral US methods was recorded.

Conclusion: To summarise, the US is a comprehensive and innovative imaging technique that is currently undergoing substantial investigation in the field of dentistry. The device is a safe, efficient, portable, cost-effective, and non-ionizing device that can be effectively used in dentistry.

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Introduction

Ultrasound has applications in a wide range of industrial and medicinal contexts. In medical imaging, it is widely recognized as a crucial and valuable clinical tool, particularly in the field of prenatal screening and diagnosis [1]. An early instance of ultrasound application in dentistry involved the application of an ultrasonic drill designed for cavity preparation in human teeth [2]. The utilization of the US in the dental and maxillofacial region has gained popularity in recent years due to growing concerns about radiation exposure and economic constraints. Ultrasound refers to sound frequencies that are higher above the audible range, which is typically between 30 Hz and 20 KHz [3]. Diagnostic ultrasound involves the transmission of high-frequency sound waves into the body using a transducer. The echoes produced by the interaction of these waves with tissue interfaces are then detected and shown on a screen [3]. The ultrasonic transducer emits sound waves through the use of piezoelectric crystals. Piezoelectric crystals are composed of materials that exhibit the property of converting electrical information into mechanical vibrations and vice versa [4]. The primary element of the transducer consists of a slender piezoelectric crystal or substance composed of many dipoles—deformed molecules exhibiting a positive charge at one end and an opposing charge at the other—organized in a certain geometric configuration [5]. The US offers various benefits for dental and maxillofacial imaging in comparison to other advanced imaging modalities. These advantages include the absence of ionizing radiation, portability, the capacity to perform dynamic and repetitive exams, and low cost. The US has established expertise in diagnosing and treating inflammatory soft tissue problems and superficial tissue disorders in the head and neck region [3,6]. By employing a resolution transducer, the US can provide a

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more distinct visualization of the internal muscle architecture compared to computed tomography (CT) [6]. The US imaging technique can also be employed for the assessment of submandibular and sublingual salivary glands. Sialolithiasis of the parotid gland is observed as echodense patches that exhibit a distinctive acoustic shadow [5,6]. Vasculatures are identified with Colour Doppler US, which is also used to measure blood flow velocity, vascular resistance, and the surrounding morphology, also the use of ultrasound elastography (USE) has been extensively studied for many clinical purposes in recent times and has been successfully incorporated into clinical practice for certain applications, such as the evaluation of liver fibrosis or the characterization of breast lesions. Elasticity imaging, performed using USE, enhances traditional US imaging by incorporating stiffness as an additional quantifiable characteristic alongside existing ultrasound imaging approaches [7]. The objective of the study is to assess different uses of ultrasound imaging in the dental and orofacial region. A literature review was conducted to investigate the utilisation of ultrasounds in dentistry. Out of a total of 300 investigations, only 70 papers met the inclusion criteria (Fig. 1). These selected studies unequivocally indicated that ultrasound examination is extensively applicable and showing significant advancements. In specific situations, ultrasound can serve as a viable alternative to other commonly employed diagnostic procedures in dentistry, without exposing patients to radiation.

Applications of Ultrasound in Dental & orofacial region

Temporomandibular joint disorders

Ultrasound, a non-invasive imaging technology, was employed for evaluating the temporomandibular joint (TMJ) in the early 1990s using a 3.5 MHz Probe. Ultrasound has been proposed as an alternative diagnostic technique for imaging TMJ abnormalities since 1992 [8]. The imaging process involves doing transverse and longitudinal scans, which allows for the examination of the antereriosuperior joint compartment from many perspectives, including axial, coronal, and oblique views. The condyle and glenoid fossa typically exhibit increased echogenicity, while connective and muscle tissues display similar echogenicity and appear variably grey. The surface of the joint capsule strongly reflects the sound waves, resulting in the formation of a hyperechoic line. The hypoechoic appearance is observed in both the superior and inferior joint spaces [9]. To provide optimal visibility of the disc, the operator should continuously modify the location of the transducer while imaging, as the condyle moves from a closed-mouth position to an open-mouth position [10]. Emshoff et al. [11] discovered that the closed mouth, half mouth opening, and maximum mouth opening postures exhibited high specificity scores of 1.00, 0.94, and 0.95, respectively. Therefore, they determined that the US was a dependable diagnostic technique for identifying the typical location of the disc during different degrees of mouth opening. Bas et al. [12] conducted a study to assess the diagnostic efficacy of ultrasonographic imaging (USI) in temporomandibular disorders (Table 1). They discovered that USI had a sensitivity of 69%, specificity of 80%, and accuracy of 71% in detecting internal derangements, when compared to clinical diagnosis. An analysis combining multiple studies found that high-resolution US was more effective than other methods in diagnosing anterior disc displacement without reduction in the TMJ [13]. Also, the meta-analysis conducted by Su et al. [14] demonstrated that ultrasound can serve as a valuable imaging technique to complement clinical examination findings in individuals with suspected disk derangements. It is advisable to prioritize the use of high-resolution ultrasound for a comprehensive evaluation that includes both static and dynamic assessments. In a recent study conducted by Li et al. [15], it was determined that the quantitative ultrasonographic diagnostic approach had favorable diagnostic efficacy. It has the potential to be utilized for anterior disk derangement screening in future therapeutic applications. In their study, Yılmaz D and Kamburoğlu K [16] compared the effectiveness of high-resolution US to MRI in evaluating TMJ disorders. They found that the US can be recommended as a supplementary imaging method for oral and maxillofacial radiologists in assessing TMJ. Pihut M et al. [17] conducted a study to evaluate the impact of US examinations on the diagnosis and treatment planning for individuals with TMJ disorders affecting the TMJ. Ultimately, the researchers stated that the ultrasound findings revealed a greater occurrence of abnormal structural alterations in the TMJ among individuals with myofascial pain compared to what was anticipated based on clinical assessment. In general, ultrasound is reasonably effective in

evaluating the TMJ and can be utilized as a quick initial diagnostic approach.

Orofacial muscle disorders

For assessing superficial soft tissues, such as the face muscles, high-resolution ultrasonography (US) is the preferable choice as the initial imaging technique [18]. The temporalis muscle can be observed on US imaging as a narrow hypoechogenic band that is located next to the temporalis fossa's medial portion. The temporalis muscle's course can be best seen by having the patient clench, while the bone landmark is recognized as a hyperdense line. Seen as a homogeneous structure, the masseter muscle is located next to the mandible's echogenic band. The posterior digastric muscle is visualized as a hypoechogenic band situated behind the parotid gland's uniform ultrasonographic pattern. The sternocleidomastoid muscle's medial border is recognized as a highly dense, hyperechogenic line [19]. The echogenic bands, which represent the interior fascia or tendon of the muscles, are often reduced or absent in the inflamed muscle. The muscle that has been histologically confirmed to have edema seems less echogenic than muscle without edema [20]. Volk et al. [21] employed US imaging to examine the bilateral face muscles in a sample of 140 participants ranging in age from 21 to 93 years. The size of almost all muscles, with the exception of the temporalis, was symmetrical. There was a strong correlation between the body mass index and the size of the majority of target muscles. The same author applied a comparable scanning protocol to examine the facial muscles in 20 individuals suffering from chronic facial palsy. The findings revealed a notable reduction in muscle size on the paralyzed side in various muscles, including the orbicularis oris, orbicularis oculi, depressor anguli oris, depressor labii inferioris, and mentalis muscles. Nevertheless, there was no observed asymmetry in the temporalis and masseter muscles. Abe et al. [22] conducted a study to assess the reliability of US imaging in measuring facial muscle thickness. They found that the relative reliability was consistent with prior findings, but the total reliability had not been earlier documented. The measurement error for assessing facial muscle thickness may exceed that of evaluating muscle thickness in the trunk or limbs. In their study, Alfen et al. [23] presented a strategy for conducting quantitative US of facial muscles. The researchers conducted a study to evaluate muscle width and echo intensity in 12 healthy individuals and one patient with myotonic dystrophy type 1. They found that quantitative muscle US of the face muscles is possible and demonstrates a moderate to exceptional level of reliability. High-resolution US allows for the precise visualization of facial muscles, identification of any asymmetry, and fast evaluation of potential targets for therapies.

Fractures involving midfacial region

Multiple studies have been undertaken to evaluate the versatility of the US in diagnosing midfacial fractures in trauma situations. Forrest et al. [24] conducted a study with the aim of determining the significance of orbital ultrasound in evaluating the injured orbit and establishing a link between pathology and CT imaging. The study authors utilized ultrasound for the diagnosis of zygomatico-orbital complex fractures and achieved a precision rate of 94%. In another study conducted by Jenkins and Thuau [25] it was shown that the diagnostic accuracy for identifying fractures of the orbit floor was 86%. McCann et al. [26] discovered a reduced level of accuracy (85%) in the diagnosis of fractures in the zygomatico-orbital complex as compared to the studies stated earlier. Gülicher et al. [27] demonstrated that utilizing ultrasonographic monitoring of fracture healing resulted in exceptional outcomes for nearly all individuals. Friedrich et al. [28] conducted a study in which they used ultrasound imaging to evaluate the visualization of various types of midfacial fractures. The fractures that were included in their study were orbitozygomatic complex fractures, isolated fractures of the zygomatic arch, nasal bone orbital floor, frontal sinus, and complex LeFort fractures. A comprehensive evaluation was conducted by Adeyemo and Akadiri [29] to assess the diagnostic efficacy of US in detecting maxillofacial fractures. The US's ability to accurately identify orbital fractures had a sensitivity ranging from 56% to 100% and a specificity ranging from 85% to 100%. In contrast, the sensitivity of ultrasound in detecting nasal fractures was between 90% and 100%, with a specificity of 98% to 100%. The US has a sensitivity and specificity of 90% in detecting zygomatic fractures. The sensitivity and specificity for mandibular fractures ranged from 66% to 100% and from 52% to 100%, respectively [29]. Rajeev et al. [30] evaluated the diagnostic precision of the US in detecting superficial facial fractures. They determined that the US examination exhibited superior sensitivity compared to traditional radiography for identifying such fractures. Blessmann et al. [31] found that the US is a reliable method for seeing the zygomatic arch, although

assessing the orbital floor is challenging. Shah et al. [32] conducted a study to assess the diagnostic precision of the US as a major tool for diagnosing maxillofacial injuries. The study aimed to estimate the specificity and sensitivity of US, validated by a CT scan. The diagnostic sensitivity for maxillofacial fractures was 85.21% and the specificity was 100%. Gadicherla et al. [33] conducted a meta-analysis to investigate the combined sensitivity and specificity of the US in detecting maxillofacial fractures. They concluded that ultrasound demonstrates high diagnostic accuracy in evaluating fractures of the orbit and nasal bones.

Salivary Gland Disorders

Tumors

The predominant benign tumors of the salivary glands include adenolymphoma, pleomorphic adenoma, basal cell adenoma, myoepithelioma, and papillary cystadenoma. The predominant malignant tumors of the salivary glands include mucoepidermoid carcinoma, adenoid cystic carcinoma, acinic cell carcinoma, and adenocarcinoma [34]. Benign lesions are typically characterized by their small size, clear boundaries, and lack of association with enlarged cervical nodes. In contrast, malignant lesions sometimes exhibit irregular shapes and have varied internal structures [35]. Malignant nodes can be identified by their spherical shape, lack of uniformity, absence of normal hilar structure, irregular and chaotic blood vessel patterns, presence of cystic changes, and spread beyond the capsule [36]. Liu et al. [34] conducted a comparative analysis using US, CT, and magnetic resonance imaging to differentiate between different types of salivary gland cancers in clinical settings. The diagnostic accuracy in the US is typically high because most salivary gland tumors are benign. In certain instances, such as when there is a substantial mass located in a deeply situated lobe of the salivary gland, the process of distinguishing between multiple possible diagnoses using USI might be challenging. A further cross-sectional investigation showed that USI was ineffective in reliably visualizing the invasion of deeper neighboring anatomical regions in patients with salivary gland tumors [37]. Li et al. [38] assessed a group of 48 patients diagnosed with acinic cell carcinoma of the parotid gland. These patients received preoperative ultrasound and CT scans. The US characteristics of the majority of acinic cell carcinomas closely matched the CT characteristics in terms of border definition, echotexture, and density on contrast-enhanced scans. Nevertheless, when it came to form, there was a distinction. Their forms were asymmetrical on the US and symmetrical on CT scans. Ishii et al. [39] conducted a retrospective comparison between the US and histologic examination of surgical specimens of palatal malignancies. The US has been demonstrated to be a valuable method for preoperatively assessing patients with small palatal tumors measuring less than 3 cm in diameter. Rinast et al. [40] accomplished a study on 41 patients with salivary gland disorders using digital subtraction sialography, conventional sialography, high-resolution US, and CT. Their findings revealed that the US had a sensitivity of 100% in detecting salivary gland masses. Wu et al. [41] did a study with the objective of examining the utility of the US in distinguishing between benign and malignant parotid tumors. They discovered There were no significant changes in the sonographic features of parotid masses between benign and malignant lesions. US-guided fine needle aspiration (FNA) or core biopsy is recommended for achieving a definitive diagnosis.

Sjögren's syndrome

Primary Sjögren's syndrome (PSS) is a persistent autoimmune disorder that specifically targets the exocrine glands. Research suggests that the results obtained in the US have a high level of specificity for PSS [42]. It is advisable to use linear ultrasonic probes with frequencies ranging from 7 to 12 MHz for the evaluation. The rheumatologist who conducts the musculoskeletal US already has access to a large range of such probes [43]. In their evaluation of salivary gland US as a substitute imaging modality for sialography in the diagnosis of Sjögren's syndrome, Takagi et al. [44] concluded that the submandibular US is a technique that shows promise and can be applied as a workable substitute for sialography in the diagnosis of Sjögren's syndrome. Obinata et al. [45] evaluated the US, histology, and sialography to diagnose Sjögren syndrome. For sialography, the sensitivity was 83.3%; for US, it was 77.8%; and for histology, it was 63.9%. Salivary gland US is a non-invasive, straightforward, and cost-effective technique for examining superficial anatomical structures, such as the parotid and submandibular glands, in great detail. Therefore, it is currently the preferred imaging method for assessing the main salivary glands in individuals with PSS [46]. In recent years, salivary gland US has not only been used for diagnosis, but also for monitoring disease activity and assessing lymphoproliferative

illnesses connected to PSS [47]. Moreover, salivary gland US could serve as a valuable tool in biopsies to guarantee sufficient histological samples in PSS patients with suspected lymphoma, hence paving the way for novel avenues in clinical research [48,49].

Inflammatory and obstructive diseases

The presence of acute inflammation results in swelling and a deviation from the typical glandular homogenous brilliant echotexture. Ultrasound can detect hyperreflective microbubbles of gas in cases of suppurative sialadenitis, along with reactive nodes in the surrounding area [50]. A study conducted by Chandak et at. [51] revealed that the majority of the inflammatory swellings exhibited distinct borders, low echogenicity, and uniform ultrasonic structure of the lesions. When it comes to identifying inflammatory swellings, the US had a sensitivity of 97% and specificity of 100%. In comparison, clinical diagnosis had a specificity and sensitivity of 85.7%. Modern, innovative, compact high-frequency ultrasonic probes enable the examination of the ducts in both the submandibular and parotid glands using an intraoral method. Transcutaneous extra-oral US is a simple and secure imaging method that has been implemented for the identification of calculi in the salivary glands. It was determined that it has the same level of effectiveness as sialography in detecting calculi with a diameter of 2 mm [52]. When comparing sialography to the US, multiple outcomes were reported. While certain papers suggested that the US is inferior or at the lowest comparable to sialography in diagnosing certain salivary gland conditions [53–55], others asserted that it holds equal [56,57] or even greater diagnostic value [58,59]. The US is an effective tool for identifying obstructive salivary gland diseases, such as sialolithiasis (salivary gland stones) and stenosis (narrowing of the gland's duct). The US imaging may not usually allow for clear differentiation of the many illnesses linked to sialodochitis. It is an effective first diagnostic tool for identifying obstructive and inflammatory illnesses of the salivary glands. In the context of obstructive diseases, diagnosis accuracy exceeds 90% in the majority of cases. The US is a highly effective screening tool for inflammatory illnesses and can be utilized to diagnose instances with early suspicion [60].

Lymph node examination

Lymphadenitis is characterized by the enlargement of lymph nodes, with a measurement of more than 10 mm in axial diameter and a shape that is either ovoid or spherical. Benign lymph nodes often exhibit an ovoid or elongated shape, accompanied by an echogenic hilum, and measure between 0.1 and 2.5 cm in length, until they exhibit calcifications or demonstrate cystic degeneration [61,62]. On the other hand, tumors that are very likely to have spread to other parts of the body are typically circular, usually appearing darker on ultrasound, and show a lack of the central part. Additionally, they may exhibit calcifications or the formation of fluid-filled sacs. Typically, these lymph nodes are situated in the lower portion of the neck [63]. De Bondt et al. [64] conducted a meta-analysis to compare the efficacy of different imaging techniques, including ultrasound, US-guided FNA cytology, CT, and magnetic resonance imaging, in detecting lymph node metastases in patients with head and neck cancer. US-guided FNA cytology was determined to be the most dependable imaging method for evaluating the existence of metastases in cervical lymph nodes among patients with head and neck cancer. In a study conducted by Ogassavara et al. [65], the morphometric patterns of lymph nodes in the head and neck of young and middle-aged individuals were evaluated. The researchers concluded that ultrasound can accurately determine the location, size, and echogenicity of lymph nodes in the face and neck of both males and females.

US in dental implants

The visibility of structures in ultrasonic imaging is determined by the ultrasound frequency, which determines image resolution, the scanning angle, and the scanning mode, as it relies on sound reflection. High-frequency ultrasonic transducers have the capability to offer superior picture resolution, which has the potential to enhance the interpretation of implant structures [66]. Culjat et al. [67] conducted an *ex vivo* investigation which showed that US can effectively identify, localize, and quantify dental implant fixtures, as well as evaluate the thickness of the surrounding soft tissue. Another ex vivo investigation showed that a 2-D sector scanning ultrasonic system was able to capture imaging representative characteristics for implant treatment preparation in an animal model [68]. A novel ultrasonic device, equipped with a transducer specifically designed to match soft tissue, a specialized

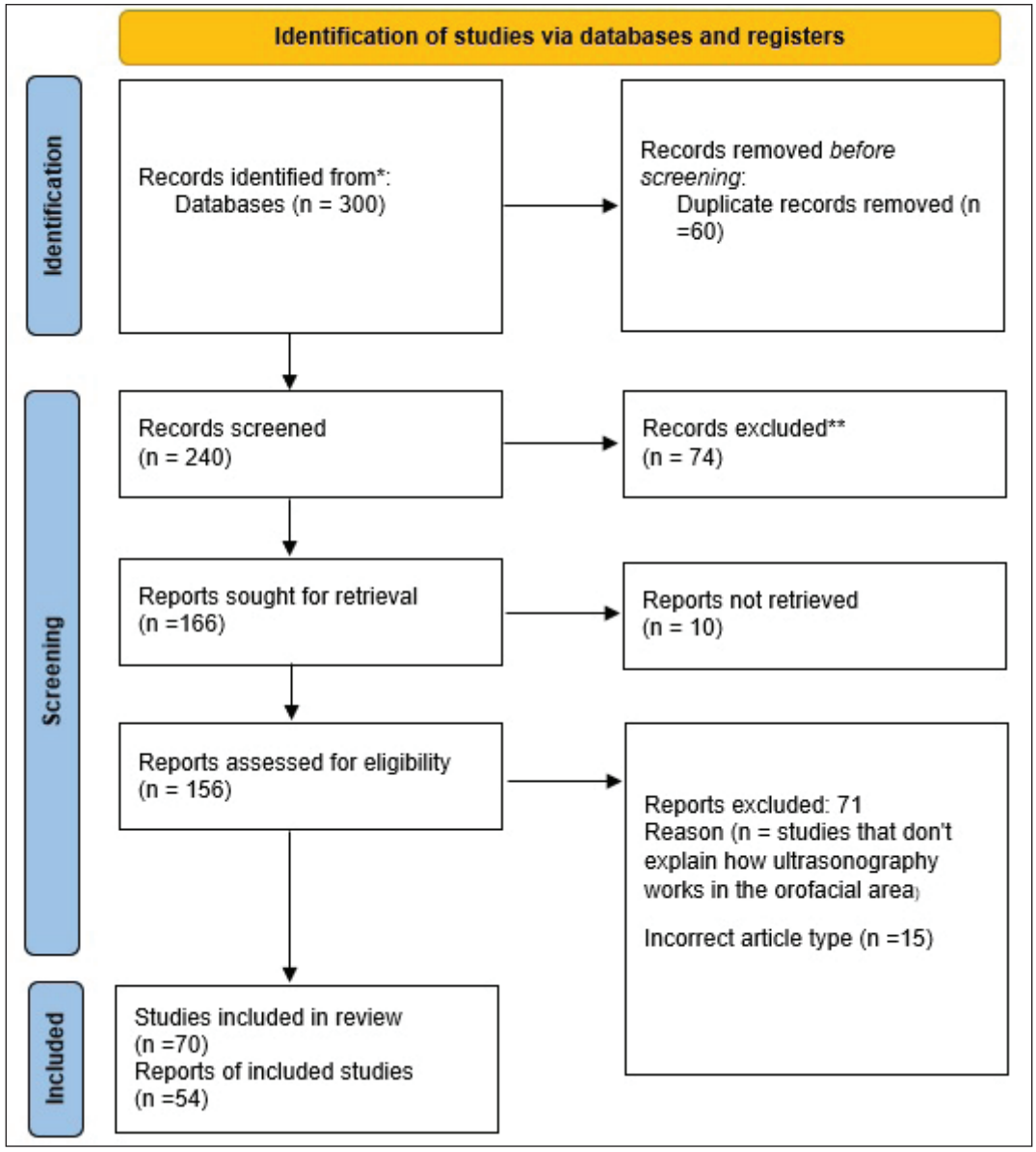


Figure 1. Prisma flow diagram for systematic review [Curtesy: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021; 372:n71; doi: 10.1136/bmj. n71].

trans receiver, and advanced signal processing capabilities, was able to accurately measure the thickness of soft tissue over bone and implants in porcine models [69]. US is a highly effective method for assessing tissue biotypes, with a measurement variance of less than 10%. The width of the ridge before surgery can presently only be determined using Cone Beam CT. Preclinical evidence indicates that the US has the capability to visualize the surface topography of ridges and thus assess their width [70]. An experimental investigation was conducted using rabbits to examine the US's ability to detect implant-bone connections. The US response exhibited a range of variability, ranging from 7% to 40%, depending on the duration of the healing process. The findings also demonstrated a correlation (R^2 = 0.45) between the US and the contact between the implant and the bone [71]. The literature has recently documented the US as a promising imaging technique for evaluating peri-implant tissue. Therefore, it can be found that high-frequency dental US is capable of screening abutments and implant fixtures [70–71]. Confirmation of the intraoperative drill bit placement is achieved through the use of intraoral radiographs during the implant operation. US can identify the variations in impedance between the cancellous bone and the surrounding cortical bone, making it a potential alternative

Table 1. Studies included in the review.

Study title	Year	Types of transducers/ Frequencies	Results/ Conclusion
The role of orbital ultrasound in the diagnosis of orbital fractures	1993	Elscint ESI transducer/ 5-10 MHz	Orbital ultrasound is a precise diagnostic technique for investigating orbital trauma and shows a strong correlation with CT scan results.
Ultrasonography in the investigation of salivary gland disease	1993	high-resolution scanner with a linear 7.S-MHz	Ultrasound should be considered a reliable initial imaging method for the majority of salivary gland diseases.
Ultrasonography evaluation of bone lesions of the jaw	1996	EUB-500 sonography (Hitachi Medical Corporation, Tokyo, Japan)/ 7.5 MHz frequency	Based on the findings, it is recommended that utilising ultrasound as a supplementary diagnostic tool for detecting abnormalities within the jaw bones.
The role of ultrasound in screening patients referred for sialography: a possible protocol	1996	5 MHz transducer	It is advisable to perform an initial ultrasound scan who have symptoms indicating an inflammatory lesion in the salivary glands.
Ultrasonic determination of gingival thickness. Subject variation and influence of tooth type and clinical features	1996	SDM ultrasonic measuring device / 5 MHz	The ultrasonic instrument demonstrated good validity and reliability in detecting gingival thickness.

to radiography for preventing surgical problems [72,73]. Monitoring the level of marginal bone and the stability of the implant is necessary during the healing and maintenance phase to ensure the success of the implant. Peri-implantitis, characterized by marginal bone loss, is predicted to affect approximately 20% of patients [74]. Bertram et al. [75] were amongst the early researchers, maybe the first, to capture images of the bone level around dental implants in people. They achieved this by employing a 12.5 MHz linear array ultrasonic probe. The US has demonstrated the ability to detect bone loss at this particular frequency. Increasing the frequency can enhance the clarity of the images and potentially enhance its diagnostic capabilities.

US in periodontology

The US has become a valuable technique for assessing periodontal health without the need for intrusive procedures. It provides real-time information on several clinical aspects, including pocket depth, tissue thickness, attachment level, histological changes, calculus, bone morphology, and tooth structure for detecting fracture [76]. Spranger pioneered the use of US in periodontology by attempting to ascertain the height of the alveolar crest in patients with periodontal disease [77]. Eger et al. [78] evaluated the quantification of gingival thickness by employing ultrasonic equipment equipped with a 5 MHz transducer. Although these endeavors have shown the practicality of using ultrasonic imaging in dentistry, researchers established that ultrasonic devices can detect echoes originating from the solid structure of the tooth surface, allowing for the determination of the level of periodontal attachment. Precisely identifying the cementoenamel junction (CEJ) is crucial for assessing periodontal health measures, including as gingival recession and clinical attachment level. US has lately been employed for direct visualization and identification of the CEJ as well as other dental and periodontal structures [79–8]. Tattan et al. [81] conducted a clinical investigation to assess the correlation and precision of US in evaluating periodontal dimensions, in comparison to direct clinical and CBCT approaches. The inter-rater correlation coefficient between ultrasound and CBCT in their findings varied from 0.654 to 0.849 throughout the tested parameters. This suggests that USI can be a beneficial tool for precise and immediate periodontal diagnosis. Another investigation was conducted by Moore et al. [82] to assess the effectiveness of ultrasonographic image-based assessments of gingival height and alveolar bone level in monitoring periodontal health and disease. The interexaminer bias for US image analysis was minimal, measuring less than 0.10 mm for the imaged gingival height and 0.45 mm for the imaged alveolar bone level.

This demonstrates that US has a comparable diagnostic capacity to the gold-standard physical probing for periodontal metrics, while providing more comprehensive anatomical information. Figueredo et al. [83] also conducted a clinical investigation to assess the accuracy of measuring interlandmark distances on intraoral US images of the periodontal tissues in a sample of 64 individuals. Their findings demonstrated that US exhibits a high level of reliability in both intra-rater and inter-rater evaluations. The results indicate that intraoral US may have promise for evaluating the periodontium. US has been reported as a highly precise and accurate method for measuring gingival thickness. It is not surprising that the US has been utilized in medicine to evaluate soft tissue with high precision. Recent research has examined the utilization of USI in evaluating the thickness of the gingiva [83–85]. Presently, the available techniques for evaluating gingival thickness consist of invasive approaches, such as inserting a probe or needle after administering local anesthesia, or non-invasive ocular assessments, which are not dependable [86]. When compared to direct tissue assessment, US has been demonstrated to be a trustworthy method in edentulous patients [87]. The current scanning duration is 1 minute per tooth. However, it is possible to design an automated probe placement system in the future that can achieve full mouth scanning in about 5 minutes. By employing this method, it is possible to conduct a comprehensive assessment of periodontal patients with a high rate of data processing at both the initial and subsequent visits [81–87].

US in Paediatric and Restorative Dentistry

The X-ray technique is the most commonly employed non-destructive examination method in the field of pediatric dentistry. Radiographs are essential tools in the dental care of newborns, children, and teenagers, enabling dentists to identify and treat oral conditions that are not visible during a regular clinical examination. Recently, US has emerged as a valuable technique in pediatric dentistry, particularly for impalement-related damage to the oral cavity and for early diagnosis of dental caries [88,89]. Recent endeavors have been made to utilize US for the purpose of discerning the internal structures of dental hard tissues. A study documented the use of high-frequency US imaging to quantify enamel thickness [90]. High-frequency USI was demonstrated to yield a high-resolution three-dimensional depiction of the enamel-dentin junction [91]. Kim et al. [89] utilized high-frequency US to assess the dimensions of caries, specifically comparing them to data collected by CT scanning. The highly encouraging outcomes enable us to see this approach as highly viable for investigating the dimensions of caries, once probes suitable for this purpose become accessible. Knowing the precise size of the caries enables us to determine the most appropriate method of restoration for the given patient during rehabilitation. El-Saadany et al. [92] conducted a clinical study to assess the effectiveness of US-based welding (Sonic weld Rx) for fixing biodegradable plates in pediatric mandibular fractures. The study evaluated both clinical and radiological outcomes in patients aged 2 to 10 years who underwent open reduction and internal fixation for mandibular fractures. The findings indicate that the US-based welding process was successful in treating pediatric mandibular fractures. Imaging the TMJ in pediatric patients is an essential element. US scans are useful in specific cases to assess the structure of joints in children and detect inflammation, as well as assist in administering therapeutic injections [93]. US can be valuable in promptly identifying pathological diseases and in providing a more precise diagnosis and suitable therapeutic management for pediatric patients with Juvenile Idiopathic Arthritis and potential TMJ involvement, with the use of MRI [94]. Recent studies indicate that ultrasound imaging enables more accurate visualization of the dental arch in the foetus and can be performed between the 14th and 28th weeks of gestation. Dental anomalies can serve as an indication for diagnosing other congenital problems, especially in cases where there is a lack of additional physical anomalies such as ectodermal dysplasia and Binder syndrome [95].

US in Prosthodontics

Despite the advancements in digital technology, particularly in digital impression-taking systems, the digitization of subgingival preparation margins without exposing the gingiva is still a challenge. This is due to the limited ability of optical waves to penetrate gingival tissue. High-frequency US-based micro scanning can serve as a non-invasive imaging technique that offers an alternative to intraoral scanning for capturing high-resolution images of prepared teeth [96]. Marotti J et al. [97] conducted an *ex vivo* investigation to evaluate the precision of US imprints obtained of teeth in

subgingival preparation, in comparison to digital optical impressions. The US scanner successfully identified the subgingival preparation margins. However, the accuracy of these scanners is lower compared to traditional optical scanners in uncovered areas, it may be inferred that the thickness of the gingiva may significantly impact the accuracy of US scans. In another investigation conducted by Praça et al. [98], it was demonstrated that the ultrasound scanner could create digital impressions of prepared teeth through porcine gingiva. However, the accuracy of fit was found to be more difficult compared to traditional optical scanners that did not have coverage of the finish lines. Recently, researchers have explored high-frequency US-based microscanning as a potential substitute for optical intra-oral scanning. US has lower sensitivity when it comes to detecting oral fluids and can penetrate the gingiva without the need for invasive exposure of sub-gingival preparations [98,99]. Heger et al. [99] conducted a study to assess the precision of US-based micro-scanning for reconstructing tooth geometry in a laboratory setting. Their conclusion was that US-based tooth digitization can serve as a viable alternative to optical impression-taking in terms of accuracy. Overall, the use of high-frequency US in micro scanning has the potential to be a patient-friendly and effective method for digitizing prepared teeth.

Conducting comparative research on different systems used in oral USI is essential to establish a consensus or guidelines that can assist physicians in making informed decisions when selecting a certain type of equipment.

Future Perspective

US is currently not widely utilized in clinical settings. The primary goal of such a system should be to minimize hardware complexity and costs, while ensuring high accuracy in working range, scanner size, scanner time, and surface reconstruction. Future endeavors should focus on the conversion of ultrasound from a research instrument to a clinical instrument. Furthermore, a focused commitment is required to incorporate USI into education for dentists and the dental community to ultimately enhance the standard of patient treatment.

Conclusion

In conclusion, US is an advanced and progressive imaging tool that is being extensively researched in the dental area. It is secure, quick, portable, and cost-effective. Despite the current absence of USI in dental practice settings, there is a persistent desire to implement this imaging technique in clinical dentistry. Additional research is necessary to explore the clinical applications of US, specifically in the oral cavity, to get accurate and appropriate information for its clinical use. Investigators, dentists, ultrasound imaging system makers, and entrepreneurs are urged to work as interested stakeholders to implement ultrasound technology in clinics, benefiting millions of patients.

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