Dentistry Review 4 (2024) 100086

Contents lists available at ScienceDirect

Dentistry Review

journal homepage: www.elsevier.com/locate/dentre

Clinical applications of ultrasound imaging in dentistry: A comprehensive literature review

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ARTICLE INFO

Keywords:
Diagnostic imaging
Ultrasonography
Ultrasonography interventional
Evidence-based dentistry

ABSTRACT

Ultrasonography (USG) is a diagnostic imaging technique based on the application of ultrasound waves with a frequency greater than 20.000 Hz, corresponding to the upper limit of audible human sound. The frequencies used in ultrasound imaging typically range from 1 MHz to 16 MHz. The principles and applications of this type of waves were first described by the Curie brothers and despite the time that has passed, their use in dentistry has not currently become widespread. The generation of images in USG is the result of the relationship and behavior experienced by different bodies and structures before the application of ultrasound pulses. Ultrasound imaging and its different modes have been used in different areas of dentistry, surgery, and maxillofacial aesthetics, in the description of cysts and tumors, identification of caries, dental fractures or cracks, periodontal bone defects, maxillofacial fractures, temporomandibular disorders, evaluation of periodontal and peri-implant tissues, in addition to the identification of anatomical structures in the facial region. Although USG in dentistry offers considerable advantages over other frequently used diagnostic imaging techniques, further research is still required in relation to the equipment used for the study of the maxillofacial area, the different tissues and anatomical spaces that are part of it.

1. Background

Ultrasonography (USG), also known as real-time ultrasound imaging or sonography, is defined as a diagnostic imaging technique based on the application of ultrasound (US) waves with a frequency greater than 20,000 Hz, corresponding to the upper limit of audible human sound [1]. Electromechanical transducers produce ultrasonic waves utilizing a piezoelectric crystal that converts electrical impulses into high-frequency sound waves, this technique is called reciprocal piezoelectric effect. These waves are transmitted to the tissues being examined. Most medical applications are based on the observation of internal body structures such as tendons, muscles, joints, vessels, and organs [2].

The Curie brothers were the first to describe the principles and applications of this wave type in 1880. Years later, in 1937, USG imaging was reported in the literature from the experiments of the Dussik brothers [3] Although there are records from the early 1960s of the use of a transducer in the visualization of dental structures [4] and in the measurement of periodontal tissue thickness [5], the use of USG in dentistry has not yet become widespread.

Scientific advances in recent years have focused on obtaining images of higher quality and resolution, in addition to reducing the patient's exposure to radiation. Magnetic resonance imaging (MRI) and USG represent the most interesting evolution in this regard, with results suggesting a promising future [6]. USG has become increasingly popular in the dento-maxillofacial field, as it does not use ionizing radiation and therefore can be safely used as a primary imaging technique for clinical

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https://doi.org/10.1016/j.dentre.2024.100086
Received 17 January 2024; Received in revised form 17 February 2024; Accepted 6 April 2024
Available online 12 April 2024

investigation and treatment. Compared to the commonly used diagnostic imaging techniques that emit ionizing radiation, such as panoramic imaging or cone beam computed tomography (CBCT), it is more economical and less invasive from the patient's perspective.

The aim of this comprehensive literature review is to describe the current evidence regarding the applications of ultrasound imaging in dentistry.

2. Materials and methods

An electronic search was conducted on PubMed (MEDLINE). The following search terms were used, including Boolean operators: ((ultrasonography[MeSH Terms]) OR (ultrasonography) OR (ultrasound) OR (sonography) OR (echography) OR (echoscopy) OR (sonogram) OR (sonography)) AND ((facial) OR (maxillofacial) OR (maxilla) OR (maxillas) OR (maxillae) OR (maxillary bone) OR (maxillary bones) OR (jaw) OR (jaws) OR (mandible) OR (lower jaw) OR (upper jaw)) AND ((hard tissue) OR (soft tissue) OR (dental implant) OR (teeth) OR (tooth) OR (gingiva) OR (temporomandibular disorder) OR (muscle) OR (fracture) OR (esthetic) OR (aesthetic)) NOT (Animals[MeSH Terms]).

The inclusion criteria were articles that included adult human (≥18 years) clinical studies investigating the use of imaging USG in dentistry, reporting the model (brand) of the ultrasound device and the frequency of the transducer, published in English or German, between January 1, 2013, and June 26, 2023. Animal studies, in vitro studies, literature reviews, systematic reviews and meta-analyses were excluded.

The studies were investigated by screening the titles and abstracts. L. D. and R.C. finalized the inclusion of articles in this study through discussion. Additional reviewers (H.A. and M.T.) were also consulted for agreement when two independent reviewers disagreed with the results of the screening. A total of 734 articles that fulfilled the inclusion criteria on the PubMed search were selected. After title and abstract screening, a total of 57 articles were selected. The main characteristics of the included studies are described in Table 1 according to topic, author(s), country, sample characteristics, US device specifications and objectives. The complete list of references of the selected articles is available in **Supplementary File 1.**

3. Literature review of ultrasonography in dentistry

3.1. Physical principles

US imaging is the result of the relationship and behaviour that different bodies and structures experience when ultrasound pulses are applied. To understand the phenomena involved, it is necessary to know some basic physical principles related to sound waves and its generation.

- **Sound:** A sensation produced in the organ of hearing, from a vibrating elastic body, which emits a wave or series of mechanical waves, usually longitudinal, propagated through some material medium, such as air or water, until it reaches the tympanic membrane of the auditory apparatus, causing it to vibrate in, turn and then being transmitted through the middle ear to the cochlea. When a sound wave interacts with a body, the molecules of the body are slightly altered, and energy is transmitted from one molecule to an adjacent molecule. The acoustic energy moves through the tissue in longitudinal waves and the molecules of the transmission medium oscillate in the same direction as the wave [7–9].
- **Frequency:** Number of repetitions that the wave crosses at the same point in the time of one second, also defined as the time it takes for a wave to complete the cycle, as a function of the period (T) of the sine waves that make up a sound. The frequency of sound is the inverse function of the period (1/T) and its units of measurement are cycles per second (cps or cycles/*sec*) or Hertz (Hz), where 1000 cycles/*sec* = 1000 Hz = 1 KHz and 1000,000 cycles/*sec* = 1000,000 Hz = 1 MHz. The audible sounds are between 20 Hz and 20,000 Hz (20KHz) and frequencies below 20 Hz are defined as infrasound and above 20 KHz as ultrasound (Fig. 1) [7,9].
- **Ultrasound:** Sound waves with a frequency higher than can be heard by humans consist of a compression zone (high density of molecules) followed by a rarefaction zone (low density of molecules) (Fig. 2). If the force oscillates continuously, alternating compression and rarefaction zones propagate through the materials [10]. In USG, the emission of this wave beam is produced by the piezoelectric effect, which results from the electrical stimulation of certain crystals, generating a continuous, modulable, and controllable vibration [9]. These high-frequency sound waves are transmitted inside the body through a transducer, and the echoes from the tissue interfaces are detected and displayed on a screen [11]. In dentistry, ultrasound with frequencies between 3 MHz and 12 MHz is typically used [12].
- **Propagation velocity:** The speed at ultrasound is transmitted through a medium, with a value of 1540 m/s for soft tissues [6].
- **Acoustic impedance:** The resistance of the molecules of a material to the propagation of US waves, which depends on the density of the body. In solid materials, fewer acoustic waves are transmitted compared to fluids [9,11].
- **Echo:** This is the reflection that sound waves experience after striking a surface, which is a fundamental property that allows clinical assessment of deep structures using USG. A reflection occurs at the boundary or interface between two materials and provides evidence of a difference in acoustic impedance between the two. When two materials have the same acoustic impedance, an echo is not produced. If the difference in impedance is small, a weak echo will be produced, while a large difference will result in a strong echo, reflecting the entire ultrasound wave. The reflected echoes are collected by a transducer, reconverted into electrical impulses, amplified, processed, and displayed as greyscale images on a computer screen or monitor for subsequent analysis and interpretation. The most intense reflections or reflected echoes appear as white tones (hyperechoic or echogenic), typically representing bone or cartilaginous structures; moderately echogenic for glands; weak, appearing as various shades of grey (hypoechoic), typically representing vessels and muscles; and finally, black (anechoic), when there is no reflection, associated with fluids and air [6,13,14].
- **Angle of incidence:** Also known as insonation, this refers to the point of wave reflection on a flat surface compared to the guideline that a normal wave follows. Reflection is strongest when the sound wave is incident perpendicular to the interface between two tissues. However, if the angle deviates slightly, the reflection of the sound wave may be partially or completely undetected by the receiving source or transducer [9,15]. The deflection of part of the beam, depending on the ultrasound velocity at the sides of the interface, is referred to as refraction [6].
- **Attenuation:** it is directly related to depth and frequency. It occurs due to the loss of power and intensity experienced by the ultrasound beam as it progressively passes through different structures. This loss is a result of absorption, reflection, refraction and/or scattering phenomena (Fig. 3). Absorption involves the conversion of mechanical energy into heat, while scattering refers to the deviation of the direction of propagation [9,15].

3.2. Image generation

The main part of the USG equipment is a transducer or probe that serves as both a transmitter and receiver of US waves. It is placed on the patient's body surface using a layer of conductive gel to ensure acoustic coupling and eliminate air gaps. Each transducer contains crystals that generate the piezoelectric effect, usually composed of lead titanate-zirconate ceramic [11]. Although polyvinylidene fluoride and trifluoro ethylene polymers have also been employed [15]. These crystals exhibit the piezoelectric effect, converting electrical signals into mechanical vibrations and vice versa [16]. The internal arrangement of these

Table 1
Characteristics of included studies and participants.

Topic	Reference	Country	Frequency of transducer and US device	Sample Size (male, female)	Mean Age	Objective
Esthetic Medicine	Sahawatwong et al., 2016	Thailand	12.5-MHz & HDI 5000 and iu 22 (Phillips US, Bothell, Washington, USA)	NR	NR	To address a novel hyaluronic injection technique to lift the lower face.
Esthetic Medicine	Jiménez-Gómez et al., 2019	Spain	18-MHz & MyLabOne system (Esaote, Genova, Italy).	10P (10F)	60.6	To assess the mechanical and biological properties of both forms of the new injectable PRGF-based formulation.
Esthetic Medicine	Wu et al., 2022	China	NR & DUB SkinScanner V5.0 (Germany)	20P (4 M, 16F)	35.8 ± 7.4	To evaluate whether the skin barrier functions might be impaired by this treatment, revealed by skin sensitivity and exacerbation of melasma.
Esthetic Medicine	Kerscher et al., 2019	Germany	4-MHz / 7-MHz & DeepSEE (Ulthera, Inc./Merz, Mesa, AZ, USA)	22P (22F)	52.32±9.31	To evaluate skin physiology following treatment with MFU-V as well as the long-term effects of this treatment when combined with calcium hydroxylapatite filler in subjects who did not show a sufficient response to MFU-V monotherapy after 12 weeks.
Esthetic Medicine	Park et al., 2023	Korea	10-MHz & Ultherapy (Ulthera, Inc. and Merz North America, Inc. Raleigh, NC, USA)	20P (1 M, 19F)	36.9 ± 5.5	To evaluate the efficacy and safety of combined treatment with superficial MFU-V and intradermal incobutolulinumtoxin-A (INCO) for enlarged facial pores.
Esthetic Medicine	Bravo et al., 2023	Brazil	18-MHz & LogicE device (GE Healthcare)	15P (15F)	45.9 ± 9.0	To assess changes in dermal thickness following a hybrid soft-tissue filler single-session injection through a noninvasive evaluation with ultrasound.
Esthetic Medicine	Volkova et al., 2019	Russia	22-MHz & DUB CUTIS SkinScanner (Germany)	71P (3 M, 68F)	NR	To thoroughly assess via ultrasound and histological analysis, the biological effects of Recovery Spatially Modulated Ablation on the epidermis, dermis, and SMAS at 30 and 90 days after the treatment.
Esthetic Medicine	Urdiales-Gálvez et al., 2023	Spain	12-MHz & Samsung HT 30 (Samsung Healthcare Global)	15P (15F)	58.0	To present the first aesthetic and safety outcomes of a hybrid filler that combines hyaluronic acid and calcium hydroxyapatite.
Esthetic Medicine	Cheng, 2019	Taiwan	NR & Ultherapy (Ulthera, Merz, Germany)	1P (1F)	41	To present a case with moderate submental neck fullness and saggy cheeks, treated by botulinum toxin injections with the Gel-assisted depth adjustment (GADA) method, which uses microfocused ultrasound to create a personalized, minimally invasive, and image-guided treatment for laxed submental skin.
Esthetic Medicine	Babtan et al., 2021	Romania	22-MHz & DUB CUTIS (Taberna Pro-Medicum, Lüneburg, Germany)	101P Control group: 78P (22 M, 56F) Test group: 24P (10 M, 14F)	Control group: 49 Test group: 52	To assess the impact of metabolic syndrome on characteristics of skin layers in sun-exposed and non-exposed maxillofacial tissues evaluated by HFU, as a potential diagnosis and monitoring tool for the aging process.
Esthetic Medicine	Paluch et al., 2020	Poland	5–18-MHz & Toshiba iAplio 900	57P (57F)	51.5 ± 7.3	To determine intra-rater reproducibility of SWE in the evaluation of facial skin in patients qualified for minimally invasive nonsurgical facial rejuvenation treatment.
Esthetic Medicine	Chaves Bellote and Miot, 2021	Brazil	4-MHz / 7-MHz & Ulthera (Merz Aesthetics, Frankfurt, Germany)	4P (4F)	33.0	To assess the efficacy of MFU-V in improving skin laxity, leading to the slimming of the lower third of the face in women who desired to naturally improve the shape of their faces.
Esthetic Medicine	Ghorbani et al., 2020	Iran	12-MHz & Mindray (Mindray Bio-Medical Electronics Co, Ltd, Shen Zhen, China)	66P (25 M, 41F)	27.82±5.51	To report structural characteristics of the Iranian nose, in patients who underwent primary open rhinoplasty.
Esthetic Medicine	Rocha et al., 2020	Brazil	8-MHz & Vscan (GE Healthcare, Wauwatosa, WI, USA)	2P (2F)	43.5	To report the use of ultrasonography to monitor the hyaluronic acid as a filler in the face for esthetic reasons.
Esthetic Medicine	Sharobaro et al., 2021	Russia	3–8-MHz & E8Voluson E8 (Austria)	137P (16 M, 121F)	49.0 ± 0.5	To develop a clinical technique for objective estimation of exact location and degree of participation of face and neck soft tissues in age-related deformations for determine effective mini- invasive treatment techniques.
Esthetic Medicine	Shome et al., 2019	India	4-MHz / 7-MHz / 10-MHz & Ultherapy (Ulthera Inc., Mesa, AZ, USA)	50P (24 M, 26F)	NR	To describe an investigation of Ultherapy for tightening facial skin. The purpose of this study was to assess both the safety and efficacy of this treatment

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Table 1 (*continued*)

Topic	Reference	Country	Frequency of transducer and US device	Sample Size (male, female)	Mean Age	Objective
Esthetic Medicine	Werschler and Werschler	USA	4-MHz / 7-MHz / 10-MHz & Ulthera System (Ulthera Inc., Merz Device Innovation Center, Mesa, USA)	20P (3 M, 17F)	47	To evaluate the efficacy and safety of patient-specific, customized MFU-V treatment with vertical vectoring to lift and tighten facial and neck tissue.
Esthetic Medicine	Malinowska et al., 2020	Poland	48-MHz & DermaMed (Dramiński SA, Poland)	7P (1 M, 6F)	36.71	To assess the usefulness of high-frequency ultrasonography for the monitoring of laser treatment of acne scarring.
Esthetic Medicine	Li et al., 2023	China	12-MHz & E-Cube7 (Alpinion CO, Anyang, Korea)	28P (7 M, 21F)	31.2	To compare the therapeutic effects in patients treated with botulinum toxin type A with retrograde linear and traditional spot injection techniques.
Maxillofacial Fractures	Singh and Jayachandran, 2014	India	10-MHz & LA435 (Siemens Acuson Antares Ultrasound System)	40P (39 M, 1F)	34.03	To evaluate the usefulness of USG in comparison with conventional radiography and CT scan in the diagnosis of zygomatic arch and mandibular fractures.
Maxillofacial Fractures	Johari et al., 2016	Iran	7–10-MHz Medison V10 (Medison, Korea)	60P (44 M, 16F)	41.21±12.01	To compare the diagnostic performance of USG and CBCT against CT in detecting orbital floor fractures.
Maxillofacial Fractures	Nezafati et al., 2020	Iran	7–12-MHz WS80A (Samsung, Korea)	42P (29 M, 13F)	30.57±13.67	To compare the accuracy of USG and CT scan in the diagnosis of fractures (with and without displacement) in all the anatomic regions of mandibular bone.
Maxillofacial Fractures	Pruksapong et al., 2023	Thailand	7.5-MHz & LOGIQ e 2012	34P (30 M, 4F)	39.67±19.82	To show the accuracy of a linear-probe US compared to CT and plain film X-ray in diagnosis of infraorbital rim fracture.
Maxillofacial Pathology	Rastogi et al., 2013	India	7.5-MHz & Toshiba Aplio XG USG Unit (Japan)	1P (1 M)	35	To report a case of cysticercosis cellulosae in a 35-year-old male patient within the temporalis muscle mimicking temporal space infection.
Maxillofacial Pathology	Peron et al., 2021	Italy	NR & BK 5000 (BK Medical)	1P (1F)	38	To report use of a 4K-3D exoscopic system and US in a transpalpebral approach to the retro-orbital space.
Maxillofacial Pathology	Magacho-Vieira and Santana	Brazil	22-MHz & LOGIQe (GE Medical Systems, Jiangsu, China)	1P (1F)	71	To describe a rare case of migration by displacement of a hyaluronic acid filler.
Maxillofacial Pathology	Prajapat et al., 2022	India	12-MHz & Voluson 730 Scanner (GE Healthcare)	1P (1 M)	30	To report a rare case of extragingival Pyogenic Granuloma of the lower lip simulating as a vascular lesion in young male of 30 years old diagnosed by US followed by histopathological examination.
Maxillofacial Pathology	Joshi et al., 2014	India	5–9 MHz & 730 Pro-BTO8 (GE Voulson, USA)	10P (7 M, 3F)	45.1	To correlate the findings of USG and histopathology for the diagnosis of oral and maxillofacial pathology and to evaluate whether USG can be used as an adjunct in diagnosing oral and maxillofacial pathology.
Maxillofacial Pathology	Ogura et al., 2018	Japan	14-MHz & Aplio 300 (Canon Medical Systems, Otawara, Japan)	Control group: 28P (12 M, 16F) Test group: 10P (8 M, 2F)	Control group: 23.9 Test group: 72.6	To evaluate the usefulness of SWE in the diagnosis of oral and maxillofacial diseases.
Muscle evaluation and TMJD	Volk et al., 2014	Germany	5-MHz & LOGIQe (GE Healthcare, USA)	7P (1 M, 6F)	42.43	To assess the regional muscle volume changes in patients with facial palsy.
Muscle evaluation and TMJD	Keser et al., 2022	Turkey	8-MHz & Aloka Prosound 6 (Hitachi Aloka Medical Systems, Tokyo, Japan)	388P (NR M, NR F)	NR	To develop and test computer-based diagnostic tools for evaluating masseter muscle segmentation on USG images.
Muscle evaluation and TMJD	Mayil et al., 2018	Turkey	8-MHz & Aloka Prosound 6 (Hitachi Aloka Medical Systems, Tokyo, Japan)	25P (12F, 12 M)	30.68±10.49	To examine ultrasonographic appearances of Masseter Muscle in dentate and edentulous patients without Temporomandibular Disorder.
Muscle evaluation and TMJD	Zieliński et al., 2023	Poland	6–15-MHz & M-Turbo (SonoSite Inc, Bothell, WA, USA)	45 P (30F, 14 M)	24±3	To analyze the correlation between the refractive error, muscle thickness, and the bioelectrical activity of selected masticatory and neck muscles in subjects with myopia.
Muscle evaluation and TMJD	Talmaceanu et al., 2022	Romania	20-MHz & Sonotouch	102P (84F, 18 M)	29	To evaluate if the increased temporomandibular joint capsular thickness, measured by US, is associated with the presence of effusion, diagnosed using MRI imaging.
Muscle evaluation and TMJD	Arslan and Yasar et al., 2023	Turkey	7–10-MHz & Mindray DC—N2 (Mindray Bio-Medical Electronics, Shenzhen, China).	60P (60F)	NR	To evaluate the differences in the thickness and internal structure of the masseter muscle in individuals with and without bruxism by USG.

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Table 1 (*continued*)

Topic	Reference	Country	Frequency of transducer and US device	Sample Size (male, female)	Mean Age	Objective
Muscle evaluation and TMJD	Muftuoglu et al., 2023	Turkey	3–5-MHz & ProSound Alpha 6 (Hitachi-Aloka Medical, Tokyo, Japan) and 4–9-MHz & ACUSON S 2000 (Siemens, Munich, Germany)	29P (10 M, 19F)	20.37±2.19	To evaluate changes in the masseter muscle after orthognathic surgery using electromyography (EMG), US and ultrasound elastography (USE) in individuals with skeletal class III anomaly over long-term follow-up and compare with a control group.
Muscle evaluation and TMJD	Sathasivasubramanian et al., 2017	India	7.5–10-MHz & GE LOGIQP5 (GE Health Care, UK)	Control group: 30P (15 M, 15F) Test group: 27P (13 M, 14F)	Control group: 37 Test group: 36	To evaluate masseter muscle thickness in unilateral partial edentulism.
Muscle evaluation and TMJD	Zieliński et al., 2022	Poland	6–15-MHz & M-Turbo (SonoSite Inc, Bothell, WA, USA)	Control group: 19P (19F) Test group: 21P (21F)	Control group: 23 Test group: 24	To examine the correlations between masticatory and neck muscle thickness and activity versus eyeball length, retinal thickness, choroidal thickness, and intraocular pressure in healthy women versus women with myopia.
Muscle evaluation and TMJD	Toker et al., 2023	Germany	14-MHz & Aplio i800 (Canon Medical Systems, Neuss, Germany)	10P (3 M, 7F)	33.9 ± 13.81	To determine whether SWE is suitable for the diagnosis of bruxism.
Muscle evaluation and TMJD	Botticchio et al., 2021	Spain	NR & M9 Ultrasound Device (Mindray, Shenzhen, China)	17P (12 M, 5F)	22.18±1.91	To objectively assess temporomandibular joint and perimandibular muscles dimensions by means of sonographic measurements before and after dry needling (DN) in asymptomatic subjects.
Muscle evaluation and TMJD	Eraslan et al., 2020	Turkey	7.2–14-MHz & AplioTM 500 (Toshiba Medical Systems Corporation, Otawara, Japan)	42P (10 M, 32F)	25.88±10.41	To compare the diagnosis of patients with temporomandibular joint internal derangements which had been diagnosed using Research Diagnostic Criteria/ Temporomandibular Disorders (RDC/TMD) with the dynamic high resolution sonography findings.
Muscle evaluation and TMJD	Park et al., 2018	Korea	NR & E-CUBE 15EX (Alpinion Medical Systems, Seoul, Korea)	40P (20 M, 20F)	NR	To evaluate the relationship between masseter muscle thickness, facial morphology, and mandibular morphology in Korean adults using USG.
Muscle evaluation and TMJD	Kalyan et al., 2018	India	12-MHz & Philips Just-Vision	50P	NR	To evaluate the use of US in identifying TMJ with internal derangement and to access its usefulness as a diagnostic tool in patients with TMJ clicking.
Muscle evaluation and TMJD	Yalcin et al., 2022	Turkey	3.1–10-MHz / 5–15-MHz / 5–18-MHz & LOGIQ S8 XD Clear (GE Healthcare, Waukesha, WI, USA)	20P (20F)	22.1 ± 2.7	To investigate the effect of splint therapy on masseter muscle and blood flow in patients with bruxism using USG.
Muscle evaluation and TMJD	Mori et al., 2019	Japan	4-MHz & LOGIQ e V2 (GE Health Care, Tokyo, Japan)	104P (34 M, 70F)	61.3 ± 20.5	To measure age-related changes in swallowing muscles by USG as a non-invasive method.
Muscle evaluation and TMJD	Kumar et al., 2019	India	11–15 MHz & 3DX 300/ Simplex (GE)	30P (28 M, 2F)	23.2 ± 5.0	To evaluate and demonstrate the role of USG as an imaging modality of TMJ by visualizing the static and dynamic relationship of the joint, assessment of joint space and eliciting reproducibility at both open and closed mouth positions.
Muscle evaluation and TMJD	Busato et al., 2017	Italy	5–12-MHz & MicrUs ext-1H (Telemed Medical Systems, Milano, Italy)	200P (100 M, 100F)	NR	To determine whether the software for the analysis of deformation patterns has the ability to show and highlight three distinct areas and if said areas matched the sections that form the masseter muscle.
Muscle evaluation and TMJD	Ba et al., 2021	China	800-kHz & HB820D (Zefeng Medical Rehabilitation Equipment Co., Ltd, Changzhou, China)	160P Control group: 80P (43 M, 37F) Test group: 80P (42 M, 38F)	Control group: 36.0 ± 8.0 Test group: 35.8 ± 9.7	To investigate the therapeutic effects of US on pain and the findings may provide better management of the disease.
Muscle evaluation and TMJD	Gagnani et al., 2021	India	10-MHz & CV 400 (Diasonics, Milpitas, CA)	19P (5 M, 14F)	28.58±7.53	To evaluate the accuracy and effectiveness of US guided autologous blood injection for the treatment of chronic recurrent TMJ dislocation.
Localization of arteries and nerves	Laher et al., 2016	South Africa	8-MHz & SSA-510A	100P (50 M, 50F)	35.7 ± 1.9	To determine the position of the mental foramen and its relation to the mandibular premolar teeth.
Localization of arteries and nerves	Kumar et al., 2019	India	7–12-MHz & M-Turbo (Fujifilm Sonosite Inc, Bothell, WA, USA)	60P	Group I: 36.23±12.87 Group II: 31.56±12.20	To evaluate the effect of USG-guided trigeminal nerve block perioperatively in terms of pain relief, opioid consumption and adverse effects in patients undergoing such elective surgeries.

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Table 1 (*continued*)

Topic	Reference	Country	Frequency of transducer and US device	Sample Size (male, female)	Mean Age	Objective
Localization of arteries and nerves	Lakha et al., 2021	India	8–12-MHz & HD3000 Unit (ATL, Bothell, WA)	20P Group I: 10 (4 M, 6F) Group II: 10 (5 M, 5F)	Group I: 61.9 ± 5.0 Group II: 49.0 ± 5.0	To assess the correlation between the diameter of the mandibular lingual vascular canal (MLVC) as determined on CBCT examination to blood flow and arterial diameter as determined by ultrasound Doppler analysis (USG) in dentate and edentulous patients.
Localization of arteries and nerves	Sampiertro-Martínez et al., 2022	Spain	3.5–16 MHz & Midray M9 (Mindray North America, NJ, USA).	6P (3 M, 3F)	39.2 ± 16.0	To determine the exact position and trajectory of the greater palatine artert using color doppler US.
Localization of arteries and nerves	Okamoto et al., 2022	Japan	7.2–14-MHz & Aplio 300 (Canon Medical Systems Corporation, Tochigi, Japan)	40P (40F)	NR	To establish a method of measuring the hemodynamics in facial muscles in a constant way and to evaluate the hemodynamic changes in the masseter and superior orbicularis oris muscles (SOOMs) before and after exercise load in two subject groups of females of different ages.
Periodontal and Periapical evaluation	Khambete and Kumar, 2015	India	8–11-MHz & LOGIQ-500 PRO (GE Medical System, USA)	10P	NR	To evaluate the efficacy of US in differential diagnosis of periapical radiolucencies.
Periodontal and Periapical evaluation	Jaswal et al., 2022	India	7–11-MHz & Prosound a6 (Hitachi Akola Medical Ltd., Tokyo, Japan)	30P (10 M, 20F)	NR	To evaluate the efficacy of digital radiography and USG for the distinction between periapical cysts and granulomas, determines the nature and extent of the periapical lesion, visualizes the lumen of the lesion, assesses its size, content, and vascularity.
Periodontal and Periapical evaluation	Tanaka et al., 2023	Hong Kong	NR & Sonimage HS1 (Konica Minolta Ltd., Tokyo, Japan)	35P (15 M, 20F)	NR	To evaluate the practical usefulness and effectiveness of intraoral USG imaging as a clinical diagnostic tool for the detectability of the horizontal component of furcation involvement of lower first molars.

Abbreviations: NR, not reported; P, patients; M, male; F, female; MFU-V, Microfocused ultrasound with visualization; HFU, High-frequency ultrasound; TMJD, Temporomandibular joint disorders; CBCT, cone-beam computed tomography; CT, computed tomography; USG, Ultrasonography; US, Ultrasound; SWE, Shear Wave Elastography.

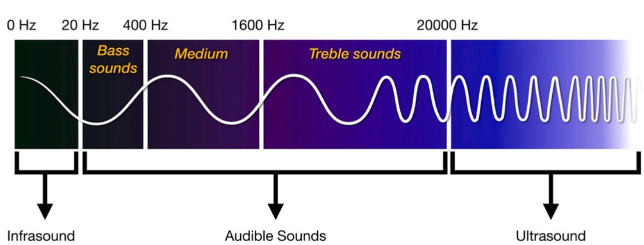

Fig. 1. Acoustic vibration spectrum.

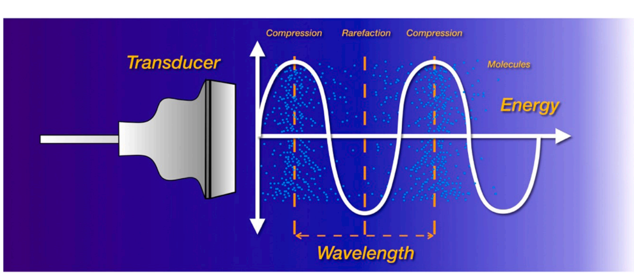

Fig. 2. Compression and rarefaction phenomena of the ultrasonic wave.

crystals determines the transducer type, such as a sectorial, annular, radial, or linear array, enabling different fields of view [9].

US emission is achieved through a transmitter circuit that generates low-voltage electrical pulses on the crystal electrodes, inducing their excitation and subsequent wave emission. These waves propagate through various tissue interfaces, generating echoes. Acting as a receiver, the transducer converts the returning echoes into small voltage

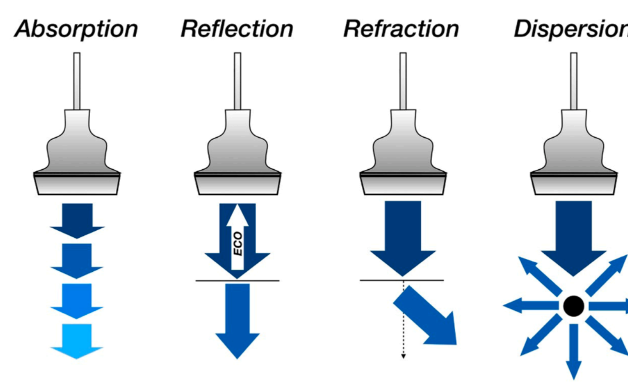

Fig. 3. Phenomena associated with the attenuation of ultrasonic waves.

waveforms or electrical pulses. By accurately measuring the travel time, the depth of the refracting tissue can be calculated using the speed of sound in the patient's tissue, typically assumed to be 1540 m/s. The resulting waveforms are then transmitted to the equipment's electronic computer for processing, which involves obtaining and assigning gray-scale values that ultimately form the image displayed on the monitor [14,17].

3.3. Advantages

In a review by Evirgen et al. in 2016 [11], multiple advantages of USG imaging were described when compared to other modern imaging techniques. These advantages include the absence of ionizing radiation, the possibility of dynamic and repeated examinations, portability, and low costs. colour doppler USG (CD-USG) is utilized to assess blood flow velocity and vessel resistance, providing additional information on the surrounding morphology. CD-USG can be considered the imaging modality of choice when X-ray examinations are contraindicated, especially in pregnant women. The fetus is particularly sensitive to the effects of ionizing radiation, which may be most significant during the first weeks of pregnancy. Unnecessary exposure to X-rays during pregnancy can increase the risk of health problems in the fetus, such as growth issues, congenital malformations, cognitive disabilities, childhood cancer, and other health conditions.

In terms of carbon emissions, US imaging has a much smaller impact than MRI and CT scans, all described as body imaging techniques, and even less than chest X-ray exams. For comparison, the carbon emissions of an MRI scan are equivalent to driving a new European car for 145 km, a CT scan for 76 km, and a chest X-ray for 6 km. In contrast, a US scan results in only 4 km of equivalent carbon emissions. The larger carbon footprints of MRI and CT scans primarily stem from electricity use, particularly their standby power consumption [18]. Additionally, USG's portability eliminates the need for constant electricity supply, as USG equipment is now available in various sizes and configurations, ranging from handheld devices to high-end systems [19].

3.4. Disadvantages

Limitations related to viewing structures are determined by several factors, such as the type of probe used, the frequency of the sound waves and the depth of the structures being viewed. One limitation is the depth of penetration. The deeper the structures are from the surface, the lower the image resolution, making it more difficult to obtain clear images. Therefore, deep structures may be more challenging to visualize with ultrasonography than superficial structures. USG cannot penetrate deeper bony structures or those located behind them. Additionally, imaging cavities is difficult due to the presence of air inside them; for example, intracapsular condyle fractures and the medial wall and floor of the orbit may not be visible on USG [20]. Similarly, very deep soft structures, such as the base of the tongue or cases with facial edema and/or emphysema, may also pose challenges in visualizing bone tissue [17]. The same vision problem concept applies to patients with a greater fat volume, as deeper structures may be harder to visualize, reducing image detail and quality.

Another limitation is the dependence on an expert operator. To produce precise and dependable images, proficiency in using ultrasound equipment is crucial. Operating a USG requires the operator to possess the necessary skills and experience. To perform and analyze the results of an ultrasound examination, the operator must possess a combination of technical skills and medical knowledge. They must undergo training and have a solid understanding of anatomy, physiology, pathology, and the operation of ultrasound equipment. It is also crucial that the operator is well-versed in scanning techniques, identifying artifacts, and troubleshooting technical issues.

While ultrasonic waves can potentially damage tissues at high exposure levels and have teratogenic effects due to heat and acoustic cavitations [21], diagnostic use typically involves low intensities and pressure levels, with a very low probability of heating beyond the normal physiological range [17]. It is crucial to note that, in general, the benefits and advantages of USG outweigh the potential disadvantages. Contraindications to ultrasonography are relatively rare.

3.5. Modalities of ultrasonography

- **Mode A (Amplitude):** This is the most basic display mode after radiofrequency [21]. It graphically represents the amplitude of the reflected sound. The position of the amplitude indicates the depth of the tissue border that is reflected. Therefore, it was originally used to distinguish between cystic, solid structures, or tissue boundaries with different acoustic properties [17]. It is used exceptionally, primarily to monitor technical parameters [15].
- **Mode M (Motion):** As the name implies, it is used for the qualitative and quantitative observation of the movement of body structures and tissues, such as heart valves [17]. On the monitor, a graphical representation of the high-temporal resolution signal is generated as a two-dimensional image, with amplitude on the vertical axis and time with depth on the horizontal axis [15].
- **Mode B (Brightness):** The B-mode is the most commonly used method. In the 2D image, the different pixels are detected with different brightness gray dots, depending on the strength of the reflected signal. It allows to detect the position and direction of the ultrasound beams and, depending on the echogenicity of the tissue, this can be displayed as a grayscale image and distinguished from other structures [17]. Using dynamic B-mode, images are produced in real time by capturing multiple individual slices at a speed ranging from 15 to 60 per second [15].
- **Mode D (Doppler):** Based on the "Doppler effect," where the frequency of the reflected ultrasonic wave is modified when it encounters a moving object, this is how the equipment detects the amplitude, phase, and difference between the frequency of the emitted beam and the reflected beam, along with B-mode images [15].

In the field of medicine, this term refers to the process of measuring the speed of fluids, such as observing the flow of blood in vessels by analyzing the backscatter of erythrocytes or examining vascular lesions [22]. A color scale can be used to indicate flow direction in medical imaging. Red signifies flow towards the transducer (arterial), resulting in a higher frequency, while blue represents flow away (venous), resulting in a lower frequency. A different mode, Power Doppler, can also be utilized to measure the quantity of moving cells in a sample volume [14,15].

3.6. Applications in dentistry

USG has evolved enormously in terms of its diagnostic use in medicine. Ultra-high frequency US, which ranges between 30 and 100 MHz, has enabled the acquisition of high-resolution images of surface-level structures. This technology is used for imaging skin, blood vessels, musculoskeletal anatomy, mucous membranes, and other tissues that are small in size or thin in thickness [23].

Numerous articles have reported on the use of US on certain facial rejuvenation therapies. In several studies US was used to measure the thickness of the dermis and the superficial muscular aponeurotic system before and after minimal invasive treatments such as various laser and hyaluronic acid therapies [24–26]. However, in a study conducted by Roha et al., US was used to guide the hyaluronic acid injection in real time. The same techniques are applied to botulinum toxin therapies of the head and neck area, where US are both utilized for the guidance and validating the results of the treatment [27,28]. US can also be used as a curative instrument for skin tightening in the mid and lower facial area. It uses focused US to induce focal heating of the dermis thus promoting neocollagenesis and the contraction collagen fibres [29].

Specifically in dentistry, the last decades have marked a constant evolution of the diagnostic application of USG. It has been nearly 60 years since the initial works were reported [4,5], with unsatisfactory results. To the present day, US imaging and its different modes or types have been used in various different areas of dentistry, in the description of cysts and tumours, identification of caries, dental fractures or cracks, analysis of soft tissues, periodontal bone defects, maxillofacial fractures and temporomandibular disorders [21]. Furthermore, in recent years it has taken on an important role in the field of Aesthetic Medicine as a tool for clinicians to identify facial anatomical structures, monitor clinical manifestations, and use fillings effectively [30].

High-frequency ultrasonography (25–35 MHz) has the capacity to penetrate some solid surfaces, including enamel and dentin, allowing the evaluation of thicknesses with satisfactory results, in addition to visualizing caries lesions and cracks within tooth structures [31]. Although promising results have been obtained in detecting caries lesions, there is a lack of standardization in methodologies and are only a limited number of clinical studies [21].

At the periapical level, it has been described as a useful diagnostic tool in the evaluation of lesions and in the follow-up of postoperative healing [12,32]. The structure of lesions and the presence of vascularity on CD-USG correlates better with histopathology than routine imaging exams [33,34]. On the other hand, USG has also been described as a reliable diagnostic tool in the assessment of molar furcation involvement, with a similar performance to CBCT [35].

In the maxillofacial area, several USG studies have been carried out as a diagnostic method for pathological diseases [36] and traumatic fractures of the middle third, being easier to find when they are non-displaced and located in the infraorbital rim [37], the anterior wall of the frontal sinus and the zygomatic arch [11]. Specifically, in the diagnosis of fractures of the zygoma-orbital complex, Forrest et al. reported an accuracy of 94 % [38], while McCann et al. reported an accuracy of 85 % [39]. In agreement with previous studies, Blessmann et al. reported that with the use of this tool it was possible to visualize the zygomatic arch quite reliably, whereas the assessment of the orbital floor was more complex, as the soft tissues covering the denser structures could make it challenging to image fractures in different planes [40]. When dealing with fractures in the mandible specifically related to condyles, USG has high levels of sensitivity, specificity, and diagnostic accuracy. However, due to confounding factors like the presence of hematoma and swelling, it is still difficult to replace CT [41]. Hence, there is still a need to further improve ultrasonographic techniques, specifically developing special transducer probes for specific regions to detect fractures without difficulty [20].

In general, USG is a good diagnostic and rapid preliminary evaluation method in the examination of the temporomandibular joint, in the evaluation of intracapsular fluid accumulation [42] and the position of the articular disc by assessing disc movement in different mandibular positions during mouth opening [11,43]. Interestingly, US in low-intensity levels is utilized as a non-invasive treatment option in temporomandibular joint osteoarthritis. The articular cartilage suffers severe damage by the apoptosis of the chondrocytes, a reaction promoted by elevated cytokine content. US can reduce the excessive amounts of inflammatory cytokines, while also helps with revascularization and increases blood flow. These positive effects reduce pain and help jaw functions in patients with temporomandibular joint disorders [44]. US therapy is widely used in the treatment of myofascial pain syndrome, that is characterized by the presence of trigger points in several places of the skeletal muscle. It can significantly decrease the pain experienced by the patients of the syndrome in 15 days by undergoing US treatments daily [45]. Recent meta-analyses have suggested that high-frequency USG may be a good imaging tool to complement clinical examination findings in patients with suspected disc displacement [46], performing better in detecting anterior disc displacement without reduction than lateral and posterior displacements with reduction [46]. Furthermore, reports suggest that it holds promise as a potential diagnostic tool for bruxism, muscle activity, and blood flow [47–49] as well as in the assessment of changes in musculature after orthognathic surgery [50] and related to age [51].

In the oral cavity, the use of intraoral USG devices allows the visualization of different anatomical structures, such as the sublingual glands, submandibular ducts, tongue, lips, tonsils, and soft palate, which are nearly impossible to observe using conventional dental imaging techniques, such as orthopantomography and CBCT [3]. Another important diagnostic capability of USG is the evaluation of nerve and arterial pathways [52–54].

Determining the periodontal or peri-implant phenotype is crucial in planning treatments that involve both soft and hard tissues around teeth and implants. This is especially important when making decisions regarding fine phenotypes and analyzing images that may contain artifacts that hinder site analysis. These artifacts may be caused by the presence of endodontic posts, previous endosseous implants, or prosthetic restorations with metallic components in their structure. Recent clinical studies evaluated the accuracy of periodontal tissue thickness measurements between USG, direct clinical methods and CBCT. Using intraoral USG equipment at 24 MHz frequency, Tattan et al. [55]. obtained images of humans in vivo, reporting highly accurate correlations in soft tissue dimensions between direct clinical measurements and USG, except for soft tissue height in edentulous sites, which showed greater variability. When examining hard tissues, USG (ultrasound) is better at distinguishing thin alveolar bone than CBCT (cone beam computed tomography). CBCT often struggles to locate the level of the vestibular crestal bone due to either reduced thickness of the lingual bone table or the presence of artefacts. This is supported by studies conducted on cadavers by Chan et al. [56], and on humans by Siqueira et al. [57] and Sinjab et al. [58]. The latter additionally found that in edentulous spans, high-resolution USG and CBCT are equivalent in measuring the bony width of the ridge in the first 3 crestal millimeters. According to a 2023 systematic review by Fan et al., which examined the use of USG in measuring periodontal and peri-implant phenotype, USG may prove to be a reliable approach for monitoring periodontal and peri-implant buccal tissue when compared to CBCT and clinical measurements [59].

Finally, once the implant is in function, USG could facilitate the evaluation over time of the crestal bone level around the implants, as has been recently reported through preliminary studies, which correlated tissue perfusion with states of health or disease of the peri-implant tissues [60], as well as the blood flow of the palate as a soft tissue graft donor site and the evolution of the reparative process in the area [61].

4. Conclusions

USG in dentistry offers considerable advantages over other frequently used imaging techniques, including real-time observation of body structures, capability of repeated examinations, portability of the devices, cost-effectiveness, greater patient comfort, absence of ionizing radiation and smaller carbon footprint. With few contraindications, USG's advantages outweigh its potential disadvantages, making it a promising imaging technique in dentistry, however, more research is needed to improve the efficiency of this examination and the development of equipment specifically for studying the maxillofacial area and its different tissues and anatomical spaces.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Data availability

The datasets used in this study can be found in the full-text articles included in the literature review.

This article does not contain any studies with human or animal subjects performed by the any of the authors.

Clinical relevance

Ultrasound imaging holds considerable advantages over other frequently used imaging techniques, including real-time observation of tissues and structures, capability of repeated examinations, portability of the devices, cost- and time-effectiveness, greater patient comfort, absence of ionizing radiation and smaller carbon footprint.

CRediT authorship contribution statement

Leonardo Díaz: Conceptualization, Methodology, Validation, Visualization, Formal analysis, Supervision, Investigation, Data curation, Writing – original draft, Writing – review & editing. **Rafael Contador:** Validation, Supervision, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Helena Albrecht:** Validation, Visualization, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Mario Ibáñez:** Formal analysis, Investigation, Writing – review & editing. **Pablo Urrutia:** Validation, Formal analysis, Investigation, Writing – review & editing. **Bulcsú Bencze:** Writing – review & editing. **Mauricio Toro:** Validation, Formal analysis, Investigation, Writing – review & editing. **Gustavo Sáenz-Ravello:** Methodology, Validation, Visualization, Supervision, Formal analysis, Investigation, Writing – review & editing. **Dániel Végh:** Methodology, Validation, Formal analysis, Supervision, Investigation, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

None

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.dentre.2024.100086.

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