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REVIEW

The applications of ultrasound, and ultrasonography in dentistry: a scoping review of the literature

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Abstract

Objectives This scoping review aims to summarize the available literature on the clinical applications of ultrasonography and ultrasound in diagnostic, therapeutic, and interventional dental applications.

Materials and methods We followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses, Extension for Scoping Reviews checklist and conducted a protocol-driven scoping review of randomized controlled trials, cohort studies, cross-sectional studies, case-control studies, and case series that assessed ultrasonography or ultrasound use as a stand-alone diagnostic, therapeutic, and interventional tool in dentistry. We included studies published after 1980, study samples ≥ 10, with diagnostic, concordance, or therapeutic outcomes. We searched Ovid MEDLINE, Embase, and others (up to April 2021) and extracted information regarding study level, patient level, test or treatment level, and outcome level data.

Results Five interventional studies (related to oral medicine, temporomandibular disorders, and dental anesthesia), eight therapeutic studies (related to surgery and orthodontics), and seventy-five diagnostic studies (related to orthodontics, surgery, endodontics, oral medicine, temporomandibular disorders, restorative dentistry, and periodontology) were identified and presented in this review.

Conclusion Ultrasonography has a well-established niche in diagnostic dentistry, while therapeutic and interventional ultrasounds have a smaller, yet present, niche in dentistry. However, further research is needed to report the precise estimates of the diagnostic, therapeutic, and interventional effects.

Clinical significance Dentists are mostly unfamiliar with ultrasonography and ultrasound and their potential uses. This review maps the diagnostic and therapeutic applications of ultrasonography and ultrasound technology in dentistry and highlights the current challenges, gaps of knowledge, and research status of ultrasound technology in this regard.

Keywords Orthodontics · Surgery · Endodontics · Oral medicine · Temporomandibular disorders · Periodontology

Abbreviations

CI	Confidence interval
K	Cohen's kappa
MHz	Megahertz
r	Person's r
W/cm^2	Watts per centimeter squared
MRI	Magnetic resonance imaging

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Introduction

Ultrasound refers to inaudible sound waves with frequencies above 0.02 megahertz (MHz) [1–3]. A frequency range of 2–20 MHz is commonly used in diagnostic settings, whereas frequencies of 0.02–3MHz are frequently utilized in therapeutic applications, particularly in managing soft and hard tissue healing [3–5]. Ultrasound waves are also used for mechanical vibration of dental tools [6], particularly in ultrasonic scalers [7], or piezoelectric surgery apparatuses [8].

Use of ultrasound as a therapy for tissue healing

Ultrasound mediates its effects by generating heat and physical forms of vibration [9]. Its thermal benefits manifest primarily in soft tissue [9–11] by promoting increased blood flow while alleviating muscle spasms and localized muscular pain [2, 4, 10, 12]. Its physical effects primarily influence hard tissue and can likely be explained by Wolf's law, which states that bone remodeling occurs due to functional demand [4, 9]. Hence, it has been postulated that increased tissue generation and remodeling can be expected if an adequately regulated therapeutic ultrasound force is exerted on bone. Ultrasound would consequently promote healing and remodeling of bone wounds similar to bone remodeling caused by orthodontic tooth movement [4, 9].

Ultrasound has excellent therapeutic potential in the maxillofacial region because it has been found to stimulate and induce endochondral and intramembranous ossification; assist in osteoclast proliferation and differentiation; increase vascular endothelial growth factors which are essential regulators of angiogenesis; and aid in healing and calcium incorporation into developing bone cultures [9–11]. Further, it can help accelerate soft and hard tissue healing, thereby decreasing recovery time, pain presentation, and risk of complications, ultimately increasing the quality of life associated with treating certain conditions [9, 11]. These qualities can benefit patients with a healing disadvantage, such as smokers, diabetics, and geriatric patients [9, 11].

Diagnostic use of ultrasonography

In diagnostic ultrasonography, the reflections of sound waves are detected and interpreted through one of the A, B, time versus motion, and Doppler reading modes [3]. A-mode is where amplitude is shown versus time [13], B-mode plots reflected echoes as one- or two-dimensional images in grayscale. Doppler mode provides a color-coded assessment of blood flow direction and velocity [3, 14–17]. Time versus motion mode records a single line in a precise place over a period of time, recording the movement of an object [13]. Ultrasonography can outperform radiographic imaging to identify early-stage abnormal healing or non-healing in soft tissues and be superior in assessing topological features of bone tissue as well as the onset of bone formation and identification of other morphological features of bone [3, 14, 18]. Due to ultrasonography's mechanism of action and its attributes, its potential for clinical use in dentistry is promising.

Ultrasonography-guided intervention

Due to its real-time capacities, ultrasonography is commonly used in medicine as a guidance tool for invasive procedures such as biopsies, injections, drains, and shunts [19]. In a dental context, there are case reports of ultrasonography-guided temporomandibular injections [20], foreign body removal [21], nerve blocks [22], and implant placement [23].

This review has been conducted to summarize the diagnostic and interventional ultrasonography uses, as well as the therapeutic ultrasound uses in dentistry.

Materials and methods

We followed the established PRISMA guidelines in designing a priori protocol [24] and the report of final review [25].

Eligibility criteria

The review flow diagram is presented in Figure 1. Any primary English language study (published after 1980) of ≥ 10 patients reporting on diagnostic, therapeutic, or interventional applications of any mode of ultrasound and ultrasonography in dentistry was considered. We excluded studies that measured a combination of ultrasonography and other tools (i.e., vibration elastography) or those not applicable to average dentists (e.g., locating carotid artery).

Selection of sources of evidence

Our comprehensive search strategy is presented in Figure 1 and Supplement 1. Upon systematic de-duplication method [26] (using EndNote X9 citation management system [27]), unique records were uploaded into Covidence® [28]. Two reviewers (ME and AS) screened all titles and abstracts independently. Disagreements were resolved by consulting a senior reviewer (AA). This process was repeated during the full-text review. A table presenting exclusions at this stage is available in Supplement 2.

Data items and data charting process

Data charting was undertaken by two reviewers (ME and AS). Disagreements were resolved by consulting a senior reviewer (AA). The sensitivity, specificity, and

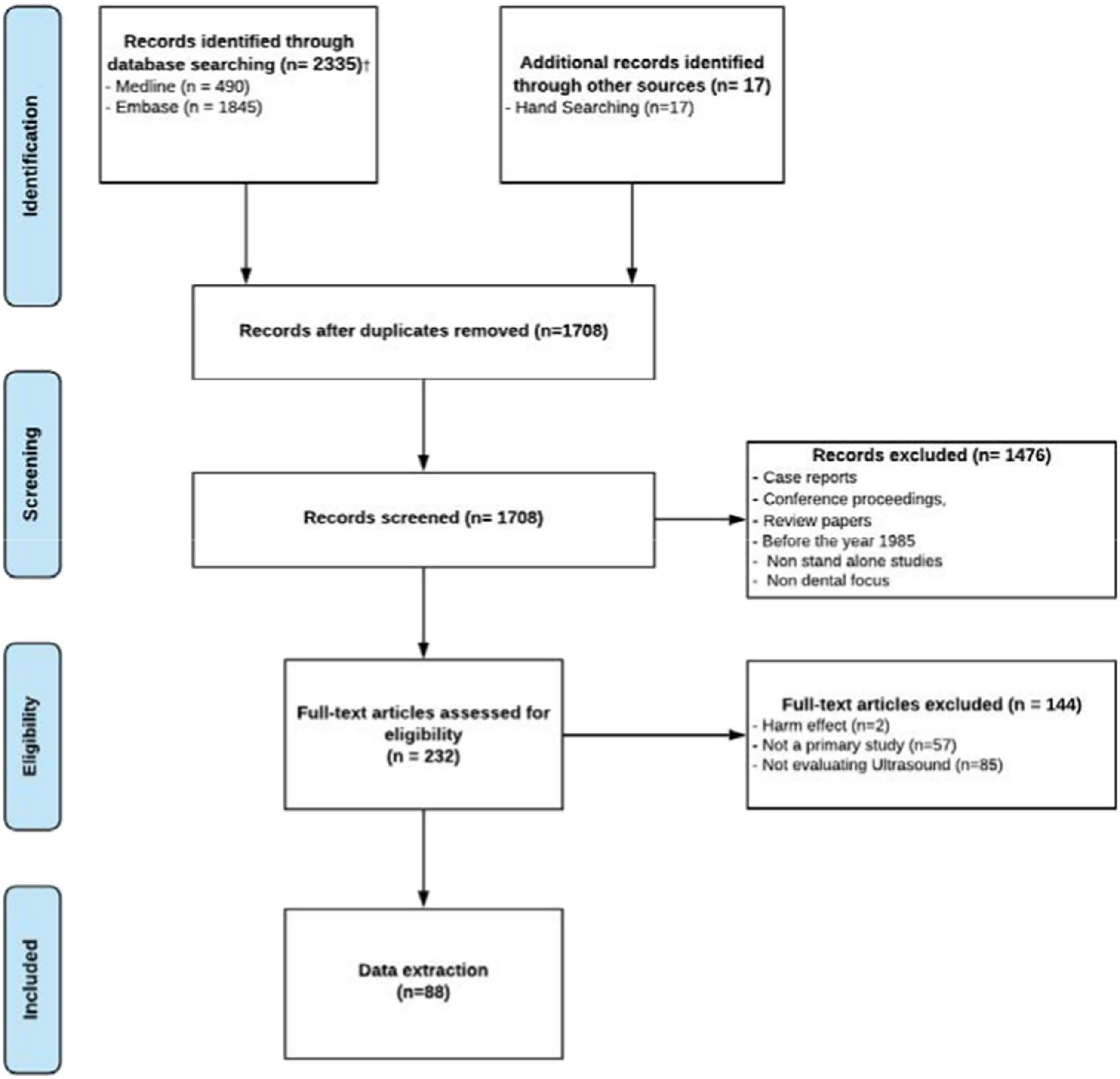

Fig. 1 Prisma style flow chart

positive and negative predictive values (PPV/NPV) were extracted or calculated if not provided [29]. Descriptive statistics on study or sample attributes, the index and reference standards, and target descriptions were also reported. Finally, bibliometric data of included articles were extracted from Web of Science™ and analyzed via VOSviewer 1.6.16 (Centre for Science and Technology Studies, Leiden University, Leiden, the Netherlands) and R Foundation for Statistical Computing (version 3.6.3, Vienna, Austria).

Results

From the initial 2,352 records, 88 articles were finally included (Figure 1). Diagnostic studies are summarized in Supplement 3, and the therapeutic and interventional studies are presented in Tables 1, 2. Although studies utilizing magnetic or piezoelectric systems to manipulate the speed or function of dental instruments were not the primary focus of this review, given their impact on dentistry, a summary is provided.

Table 1 Description of therapeutic studies

Study and location	Study design	Sample description	Treatment outcome	Comparison	Intensity	Results
Orthodontics						
El-Bialy [10] Egypt	Split mouth trial	*n*: 12; Y.O: [not provided] Ortho patients that need first premolar extraction	**Orthodontically induced root resorption:** root lacunae number; size	Control	0.03 W/cm^2	**Number of RL on buccal surface** (*p* .000007). Treatment: mean 2.5, SD 1.9, range 0–5; Control: mean 26.2, SD 3.5, range 24–32 **Number of RL on palatal surface** (*p* .0003). Treatment: mean 12.5, SD 4.6, range 7–17; Control: mean 21.8, SD 2.3, range 18–25 **Area of RL (μm^2) on buccal surface** (*p* .00001). Treatment: mean 12.3, SD 6, range 2–19; Control: mean 450, SD, 115 range 230–560 **Area of RL (μm^2) on palatal surface** (*p* .039). Treatment: mean 52, SD 21, range 18–84; Control: mean 220, SD 219, range 41–802
Kaur and El-Bialy [93] Canada	Retrospective clinical study	*n*: 34; Y.O.: 15–72; Incl: mandibular prognathism	**Treatment duration of mandibular prognathism**	Control	0.03 W/cm^2	**Low-intensity pulsed ultrasound time:** 541.44 ± 192.2 days **Control time:** 1061.05 ± 455.64 days $p < 0.05$
El-Bialy et al. [92] Canada	Split mouth trial	*n*: 34; Y.O.: 15–72; Incl: first premolar extractions for malocclusion	**Rate of tooth movement**	Control	0.03 W/cm^2	**Rate of tooth movement:** Control less by 29% **Orthodontic root resorption:** Low-intensity pulsed ultrasound < control
Raza et al. [94] Canada	Split mouth trial	*n*: 10; Y.O.:12–35; Incl: mandibular prognathism	**Orthodontically induced root resorption**: root lacunae number, volume height, and depth	Control	0.03 W/cm^2	**Root lacunae volume:** Low-intensity pulsed ultrasound < Control **Root lacunae number:** Low-intensity pulsed ultrasound < Control. [A] **Root lacunae coron-apical height and depth:** Low-intensity pulsed ultrasound < Control

Table 1 (continued)

Study and location	Study design	Sample description	Treatment outcome	Comparison	Intensity	Results
Surgery						
ElHag et al. [99] UK	RCT	*n*: 103; Y.O: 14–25; Incl: surgical extraction of 38 or 48	**Healing**: swelling vol.; trismus; plasma cortisol concentration. pain; wound healing	Control	0.5 w/cm^2	**Mean differences:** Swelling volume: 24 h: −15%, 3 days: −46%, 7 days: −57%, $p < 0.05$; trismus[?]: 24 h: −25%, 3 days: −30%, 7 days: −36%; *p* not specified; polymerase chain reaction test[?]: 24 h: −13%, 3 days: +7%, 7 days: +3%, *p* not specified
Hashish et al. [100] UK		*n*: 150; Y.O: 14–25; Incl: surgical extraction of 38 or 48		Control and placebo	0.1; 0.5; 1.5 W/cm^{-2}	**Reduction mean difference significance**: Swelling vol.: $t = 18.7$, $p < 0.01$; Trismus: $t = 17.28$, $p < 0.01$; pain: $t = 4.25$, $p < 0.01$, plasma cortisol concentration: $t = 5.78$, $p < 0.01$
Kerr et al. [103] USA	Split mouth trial	*n*: 12; Y.O.: 36–72 Inc: post non-surgical extraction sites of Incisors, premolars, or molars,	**Bone formation:** Buccal/lingual crest heights; bucco-lingual width	Control	0.03 W/cm^2	**Mean difference**[?]**:** Bone width (at 9 mm) [±]: −0.05 mm, $p = 0.7$; loss of buccal height[±]: +0.24 mm, $p = 0.3$; loss of lingual height[±]: −0.12 mm, *p* 0.6
Patel et al. [108] India	RCT	*n*: 28; Y.O.: 15-35; Incl: fresh fractures and with no infection at site or associated soft tissue injury	**Healing of fracture:** By inter-maxillary fixation	Control	1.5 W/ cm^2	**Radiographic density:** Low-intensity pulsed ultrasound > inter-maxillary fixation **Pain:** Low-intensity pulsed ultrasound < inter-maxillary fixation **Clinical mobility:** No significant difference

? Presumed/estimated/calculated based on study Text/Image/Graph

± Direction of effect; (−) resembles less than comparative target value; (+) resembles more than comparative target value

● Satisfying the criteria: unretentive, unstable dentures; < 8 mm height at mandibular canine; unsatisfactory relief with conventional dentures.

‡ Radio opacity grading range: 0 = absolute black, 100 = absolute white

[A] Distal surface but not statistically significant

Table 2 Description of interventional studies

Study and year location	Sample description	Ultrasonography-assisted procedure	Intervention	Comparison	Frequency	Results
Local anesthesia						
Hannan et al. [114] USA	*n*: 40; Y.O: 19–44	Inferior alveolar nerve block	Ultrasonography-guided injection	Injection by Landmark	[Not provided]	**Anesthetic success:** The same for all teeth except 1st molar ultrasonography < 7% ($n = 3$); 2nd premolar ultrasonography > 2% ($n = 1$); 1st premolar < 2% ($n = 1$) ($p > .05$)
[116] India	*n*: 60; Y.O: Intervention 34.066 ± 5.353 – Comparison 32.060 ± 4.094	Mandibular nerve block before mandibular fracture surgeries	Ultrasonography-guided injection	Injection by Landmark	5–13 MHz	**Morphine consumption for 24 h:** Intervention (4.566 ± 0.717 mg) – Comparison (5.93 ± 0.876 mg); $p < 0.0001$. **Additional analgesia doses needed:** Intervention (4) – Comparison (11); $p = 0.037$. **Heart rate after 30 min:** Significantly less in Intervention **Mean 0-10 VAS score 2–24 h:** Intervention (1.13–2.6) – Comparison (1.2–2.7) *p*: 0.01–0.57 **Rescue analgesic:** Intervention (794.08 ± 89.561 min) – Comparison (505.333 ± 3.159 min)
Jain et al. [115] India	*n*: 68; Y.O: 18–65	Vazirani-Akinosi nerve block for mandibular fracture, acute pain, and trismus	Ultrasonography-guided injection	Vazirani-Akinosi approach	8–13 MHz	**Block failure (continued pain [VAS > 30/100] after the block procedure):** Ultrasonography 4; Regular 6
Temporomandibular mandibular joint						
Resnick et al. [89] USA	*n*: 45; Y.O: 13.6 ± 1.3	Intra-articular steroid injection	Ultrasonography-guided injection	Landmark injection group	[Not provided]	**Resolution of pain:** No statistically significant difference **maximal incisal opening:** No statistically significant difference **synovial enhancement ratio:** No statistically significant difference **procedure time (minutes):** Unilateral Intra-articular steroid injection Comparison 34.3 ± 13.7 – Intervention 82.4 ± 29.1 $p = .008$; bilateral intra-articular steroid injection Comparison 51.1 ± 23.7 – Intervention 100.9 ± 38.2 $p = .005$

Table 2 (continued)

Study and year location	Sample description	Ultrasonography-assisted procedure	Intervention	Comparison	Frequency	Results
Oral medicine						
Wensing et al. [83] Netherlands	n: 62; Y.O: 27-90	Ultrasonography-guided fine needle aspiration cytology	Ultrasonography-guided fine needle aspiration cytology (FNAC)	Histology	[Not provided]	**Ultrasonography-guided fine needle aspiration cytology results**: True-positive: 0%?; false-positive: 0%?; true-negative: 78%?; false-negative: 22%; inconclusive node puncture: 11%?

? Presumed/estimated/calculated based on study text/image/graph

The included studies were mostly published after the year 2000, investigated ultrasonography for diagnostic imaging (n = 75), and were in the setting of oral medicine and pathology n = 41 (48%) (Figure 2). Therapeutic ultrasound applications (n = 8) and interventional ultrasonography (n = 5) were studied less frequently. The studies were conducted in India (n = 25); Japan (n = 12); USA (n = 9); Canada, Italy, Germany, and the UK (n = 5, each); Turkey (n = 4); Egypt and the Netherlands (n = 3, each); Austria and Hong Kong (n = 2, each); and least frequently in Switzerland, Korea, Israel, Iran, China, and Australia (n = 1, each).

The bibliometric data of 61 articles were identified in the Web of Science™. Using keyword co-occurrence network analysis, science™ mapping showed that ultrasonography was the most popular topic (Figure 3). Co-citation network analysis showed that the *Journal of Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Head & Neck* received the highest number of citations, followed by *The American Journal of Surgery* (Figure 4). Simultaneously, there was a growing trend for the publication of these investigations in the *Journal of Endodontics* in the last decade (Figure 5).

Use of ultrasonography in endodontics

We identified 16 diagnostic ultrasonography and no therapeutic ultrasound studies in endodontics [15, 18, 30–43].

In endodontics, ultrasonography was most frequently researched for detecting endodontic lesions [15, 18, 32–41] and the measurement of their healing [43]. In these studies, a 5–12 MHz ultrasound was compared to panoramic and periapical radiographs [42, 43], cone beam computed tomography [15, 18, 32–38, 41, 42], or histology [15, 18, 32–38, 41, 42] in samples of 10–80 patients. When compared to histology, high diagnostic metrics were noted for detecting periapical lesions (specificity, 91–100%; agreement level, 0.667 p = 0.002) [42]; however, the ranges of PPV (50–100%), sensitivity (74–100%), and NPV (26–100%) were broad and imprecise [30, 39]. When compared to radiology, ultrasonography had high diagnostic values and agreement (sensitivity, 80–92%; specificity, 97–100%; PPV, 98–100%; K, 77%; Z, 18.18) in measurements of lesion width in mesiodistal and anteroposterior dimensions [42, 43]. However, it did have a broad and imprecise NPV (26–88%) [30, 39] and significantly more conservative measurements of lesion depth, surface area, and volume when compared to cone beam computed tomography [42].

Cotti et al. [31] identified high rates of intra-observer agreement and diagnostic values in diagnosing sinus tracts (n, 20 patients; K, 1; sensitivity, 90–100%; specificity, 100%; PPV, 100%; and NPV, 91–100%) with the use of 7–12 MHz

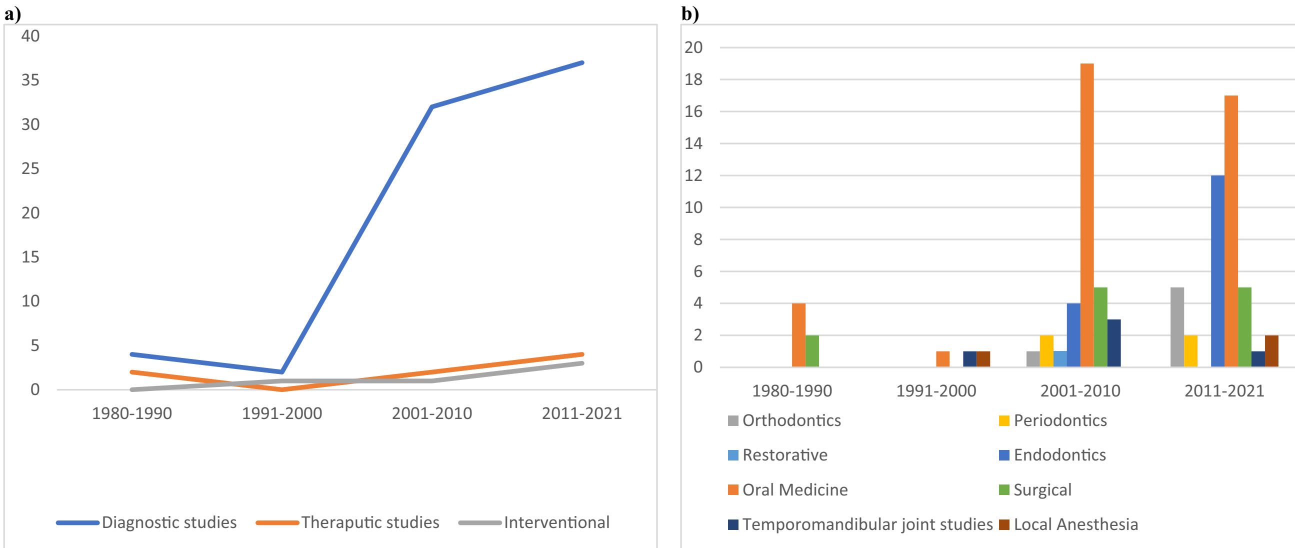

Fig. 2 Application of ultrasound in dentistry in the past 4 decades

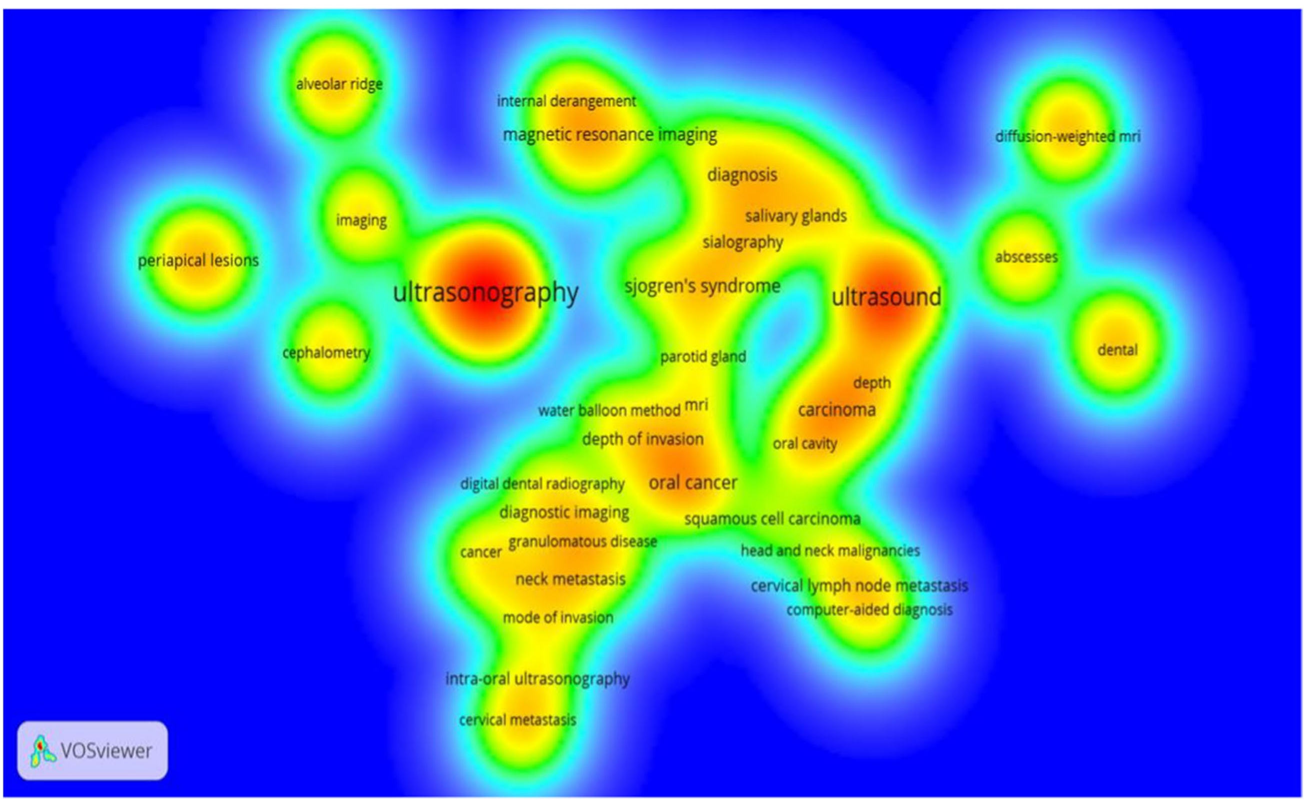

Fig. 3 Density visualization of the keyword co-occurrence network analysis showing the popular topics among included articles

ultrasonography as compared to direct observation of a stoma and sinogram tracing with gutta-percha.

Ahn et al. [30] compared 20 MHz ultrasonography to electrical pulp testing regarding the rate of detecting positive sensibility readings for 78 patients who had suffered dental trauma. Tests were conducted on the day of trauma and then after 2 weeks, 1 month, 3 months, 6 months, and 1 year. They showed that ultrasonography reported 25–49% higher sensibility readings in all time frames.

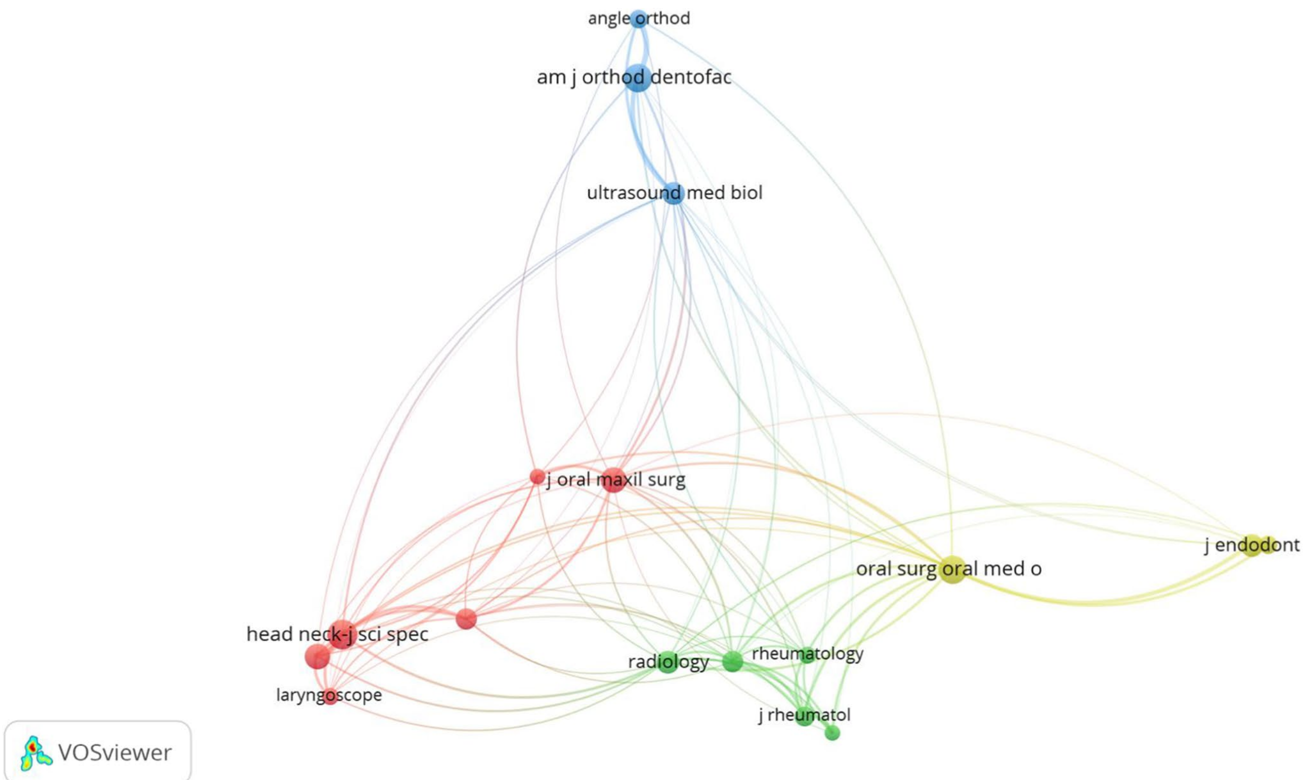

Fig. 4 Publishing *Journals of Ultrasonography*

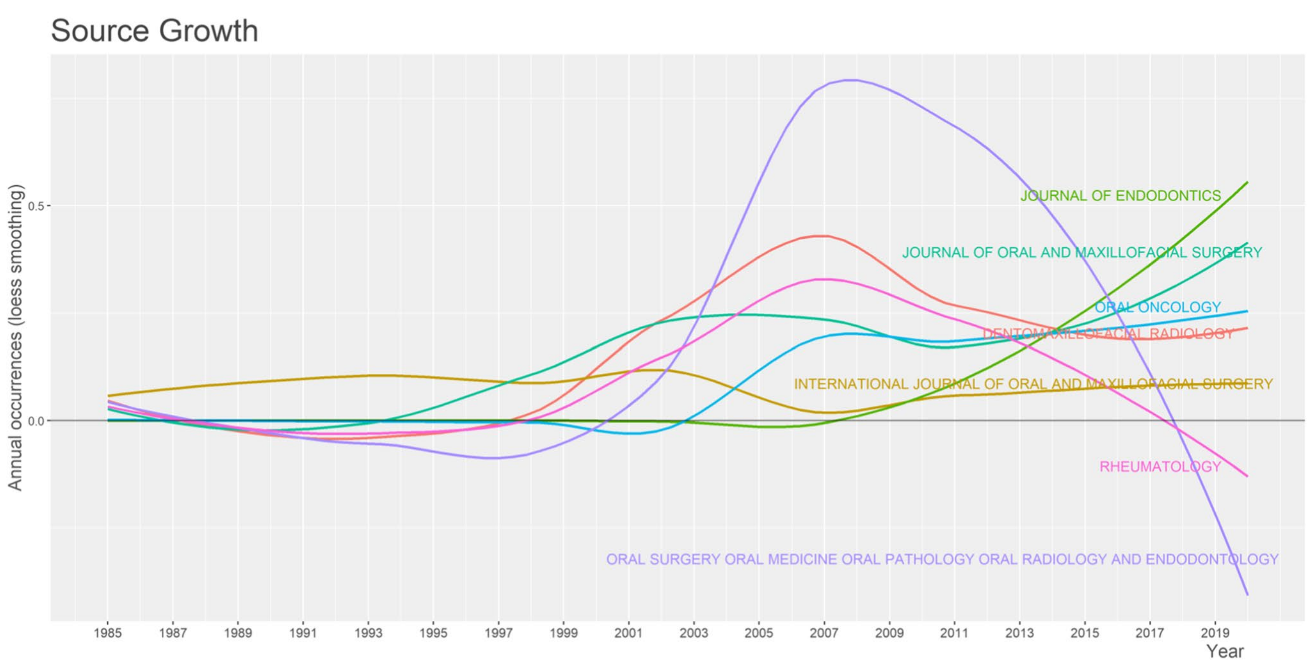

Fig. 5 Source growth

Use of ultrasonography in oral medicine

We identified 40 diagnostic studies [44–83] (Supplement 3), one interventional ultrasonography study [84] (Table 2), and no therapeutic studies in oral medicine.

In oral medicine, ultrasonography was mostly researched for the detection and measurement of hard and soft tissue oral lesions ($n = 17$) [54, 75], specifically oral malignancies [44–46, 48, 50, 51, 61, 63, 64, 68, 70–73, 76]. In these studies, 5–70 MHz ultrasonography was compared to computed tomography [54] and histology [54, 75] in sample sizes of 10–160 patients. Ultrasonography demonstrated favorable results for detecting premalignant, benign mucosal, autoimmune, and osseous intraoral lesions [54, 75]. A correlation coefficient of 0.99 was observed when compared to computed tomography for the detection of intraosseous lesions [54]. Furthermore, compared with the gold standard of histology, ultrasonography was able to detect autoimmune diseases (oral lichen planus was defined as homogeneous hypoechogenicity lesions), mucosal growths, and potentially premalignant lesions, with high rates of diagnostic values (sensitivity, 91–100%; specificity, 93–99%; PPV, 83–99%; NPV, 98–100%) [75]. With the exception of its specificity (0–100%), ultrasonography was good at the detection and measurement of oral cancer lesions (sensitivity, 86–100%, PPV, 83–100%, NPV, 97–100%) [44–46, 48, 50, 51, 61, 63, 64, 68, 70–73, 76] and correlated well with histological measurements of malignant oral masses ($R^2 = 0.74$, $r = 0.99$; $p < 0.001$) [63] and tumor thickness (Pearson's $r = 0.73–0.99$, $p < 0.001–0.05$) [58, 74], with the exception of tumor width ($r = 0.1205$) in one study [73].

The second most studied application of ultrasonography in oral medicine ($n = 12$) was in cervical lymphadenopathy in patients with oral squamous cell carcinoma [49, 57, 62, 81]. In these studies (with 19–70 subjects), 3.5–13 MHz ultrasound imaging was compared to histological measurements [56, 60, 78] and cytopathological assessments [62] and presented a wide range of diagnostic values (sensitivity, 47–100%; PPV, 67–100%; NPV, 96–100%).

The third most studied application of ultrasonography in oral medicine ($n = 11$) was identifying pathological changes and abnormalities in salivary glands [52, 59, 72, 82, 85] with a focus on Sjögren's syndrome [65]. These studies compared 3–12 MHz ultrasonography to computed tomography [57], sialography [49, 52, 56, 59, 60, 62, 78, 82], histology [78], magnetic resonance imaging (MRI) [62], and several diagnostic criteria for Sjögren's syndrome including the Revised International Classification Criteria [84] in samples of 31–360 patients. Ultrasonography demonstrated an 87% correlation with sialography in identifying calculi, duct dilation cystic elements, and gland enlargement [84], as well as a 79–94% accuracy and a 100% sensitivity in detecting salivary gland masses as compared to sialography [57, 81]. However, it only had a 54% sensitivity in detecting sialadenitis as compared to sialography [57]. The diagnostic values of ultrasonography in detecting Sjögren's syndrome were mixed (Supplement 3). When compared to sialography in detecting Sjögren's syndrome, the diagnostic values were mediocre ($r = 0.58$; sensitivity, 63–90%; specificity, 78–94%, accuracy, 74–85%; PPV, 61–82%; NPV, 70–91%) [49, 52, 56, 59, 60, 62, 78, 82]. However, compared to histological assessments in detecting Sjögren's syndrome, the correlation ($r = 0.82$) [78] and inter-observer variation (83%) [62] were very good.

Only one interventional study [84] investigated the use of ultrasonography-guided fine-needle aspiration, as compared to histological assessments, in the diagnosis of lymph node metastasis in 62 patients with oral squamous cell carcinoma (Table 2). They reported a false-negative value of 22%, and 14% of the inconclusive aspirations were found to be positive for metastasis by histopathological analysis [84].

Use of ultrasonography in temporomandibular disorders

We identified four diagnostic studies [86–89], one interventional ultrasonography study [90] (Table 2), and no therapeutic ultrasound for temporomandibular disorders.

Two studies addressed ultrasonography's ability to detect temporomandibular joint and condylar translation [86, 87]. These studies compared 10–12 MHz ultrasonography to MRI [86] and axiography [86, 87] in 47–55 patients. Ultrasonography had favorable results when compared to MRI in identifying temporomandibular joint movement (concordance of 83%) [86]. Sonography was also significantly faster than axiographic examinations, with an examination duration for identifying disc displacement and measuring condylar translation [86, 87] of 2 and 20 min [86], respectively. Measurements of joint/disk translation ranges were more conservative than axiographic, with mean differences of 0.6–3.3 mm in measuring range of motion, protrusion, and mediotrusion [86, 87]. The other two studies [88, 89] addressed ultrasound's ability to visualize and help with the diagnosis of temporomandibular joint disk abnormalities. These studies compared 7.5–12 MHz ultrasonography to MRI in 33–52 patients with mixed results. Muller et al. [88] reported a high specificity (82%) but low sensitivity (33%) in identifying juvenile idiopathic arthritis as compared to MRI. Similarly, Kaya et al. [89] reported mixed results (sensitivity, 50–91%; specificity, 16–89%; accuracy, 57–82%; PPV, 63–89%; NPV, 20–80%) in identifying different types of joint anterior disk displacement and joint effusion as compared to MRI.

One interventional study [90] compared ultrasonography-guided injection against landmark injection of steroids into temporomandibular joints of 45 patients with juvenile idiopathic arthritis. There was no difference in resolution of pain or maximal incisal opening; however, there was a significant increase in procedure time (approximately 49 min) in the ultrasonography-guided injections for both bilateral and unilateral intra-articular injections.

Use of ultrasonography and ultrasound in orthodontics

We identified two diagnostic [91, 92] and four therapeutic [2, 93–95] (Table 1) studies in orthodontics.

Two studies [91, 92] addressed the diagnostic values of ultrasonography in identifying orthodontic soft and hard tissue point measurements in samples of 11 and 20 patients, respectively. Both studies compared 13 MHz ultrasonography to cephalograms and reported significant agreement between measurements ($r \geq 0.92$–0.92) for volume, thickness, and lateral cephalogram points [91]. There was also favorable agreement and concordance values for identifying orthodontic soft and hard tissue point measurements (inter-operator agreement of $r = 0.8$–0.99; Spearman's $\rho = 0.6$–0.98; intraclass correlation coefficient of 0.83–0.98; concordance correlation coefficient of 0.82–0.98) with only a minimal ultrasonography-cephalogram point measurement mean difference of 0.06–0.70 mm [92].

Three therapeutic studies evaluated the use of ultrasound for its ability to reduce the amount and size of root resorption potentially caused by excessive orthodontic forces [2, 95] as well as the time needed for orthodontic tooth movement [93] (Table 1). These studies compared 0.03 W/cm^2 low-intensity pulsed ultrasound with a control group of conventional orthodontic treatment in samples of 10–34 patients. It was found that the use of ultrasound reduced the size of osseous resorption lacunae on the buccal surface, as seen by a mean area of root lacunae of 450 μm^2 and 12.3 μm^2 for control and ultrasound, respectively ($p = .00001$) [96–104]. Ultrasound also reduced the number of lacunae as seen by a mean count per palatal root surface of 21.8 and 12.5 in the control and ultrasound group, respectively ($p = .0003$) [96–99]. Treatment with ultrasound also accelerated orthodontic tooth movement rate by approximately 29% (0.266 ± 0.092 mm/week in the ultrasound group compared to 0.232 ± 0.085 mm/week in the control sample $p = 0.11$)[93].

One study [94] compared a 0.03 W/cm^2 low-intensity pulsed ultrasound treatment group to regular surgical treatment of mandibular prognathism in 34 patients and found that ultrasonography decreased treatment time as shown by the 541.44 ± 192.2 required treatment days in the ultrasound group and 1061.05 ± 455.64 treatment days in the control group ($p < 0.05$).

Use of ultrasonography and ultrasound in surgery

In total, we identified eight diagnostic [105–107] (Supplement 3) and four therapeutic [96–98] surgical studies (Table 1).

In surgery, ultrasonography was mostly researched for identification and differentiation between cellulitis and abscesses [96, 97], as well as edematous changes [96]. In these studies, a 4.8–12 MHz ultrasound was compared to MRI [98], surgical exploration [108], and incision and drainage [99] in samples of 16–82 patients. Ultrasonography studies demonstrated usefulness in the identification and differentiation of abscesses and cellulitis (sensitivity, 87–96%; specificity, 100%; PPV, 100%; NPV, 92–100%). The studies reported a mediocre-to-good range of correct identification of cases examined (76–90%) [101].

The second most common group of diagnostic studies addressed the topography of the bone (bone mineralization and deficiencies) [100]. These studies compared 7.5–10 MHz ultrasonography to direct clinical inspection [101], histological assessments [100], and posteroanterior radiographic imaging [104, 109] in samples of 10–32 patients. Ultrasonography's ability to identify ramus fractures was poor (sensitivity 66%; specificity 52%) [98] but correlated well (Spearman's rank = 0.76) with direct visualization of gaps in bone healing defects [96, 97].

Arimoto et al. focused on the location of the internal maxillary artery (before mandibular prognathism surgery) in a sample of 19 patients [99]. Ultrasonographic imaging could not view the internal maxillary arteries without a fenestration; however, ultrasonography imaging and measurements varied minimally from location readings obtained by way of MRI (R^2: 0.44–0.63) [99].

Two studies [100, 101] used low-intensity pulsed ultrasound therapeutically to aid in surgical extraction site healing. These studies compared 0.1–1.5 w/cm^2 to placebo [101] and regular treatment (control) [100] in 103–150 patients. The investigators found that ultrasound treatment of extraction sites reduced swelling (by 15–57% $p < 0.05$; Student's t test = 18.7, $p < 0.01$), trismus (by 25–36% p unspecified; Student's t test = 17.28, $p < 0.01$), pain (Student's t test = 4.25, $p < 0.01$), and plasma cortisol concentration (Student's t test = 5.78, $p < 0.01$) [101]. The reduction in parameters related to inflammation and pain also correlated strongly with the number of days of treatment with ultrasound. The minimum effects (15% for swelling and 25% trismus reduction) were achieved in cases only exposed within the 24 h of surgery, and the maximum effect (57% for swelling and 36% trismus reduction) was achieved when ultrasound therapy was administered daily for 7 days [100].

The other two therapeutic studies [104, 109] addressed the effects of ultrasound treatment on bone formation [104] and fracture healing [109]. Low-intensity pulsed ultrasonography at 0.03–1.5 w/cm^2 was compared to standard of care treatment in samples of 12 [104] and 28 [109] patients. No significant difference in bone mineralization, width, and height gain was noted [104]. Furthermore, no impact on clinical mobility of healed or healing fractures were noted; however, there were statistically significant increases in the radiographic density and reduced pain (evaluated by a 0–10 visual analog scale) in comparison to intermaxillary fixation without ultrasound treatment in fracture healing [109].

Use of ultrasonography in periodontology

We identified four diagnostic studies [110–113] (Supplement 3) and no therapeutic or interventional studies for periodontal treatment.

Three studies assessed the use of ultrasonography in measuring dimensions of the periodontium [113] gingival thickness [111, 112]. A-scan [111] and 10–24 MHz [112] ultrasonography were compared to cone beam computed tomography [113], trans-gingival probing [111], and digital vernier caliper [112] measurements in 20 [113] to 32 [111] patient samples. Ultrasound-generated measurements were comparable to those of cone beam computed tomography (inter-rater correlation coefficients: 0.48–0.97) [113], caliper measurements (P value 0.2–0.09) [112], and trans-gingival probing (mean difference of 0.22–0.49 mm) [111].

As compared to visual observation during surgery, the value of 12.5 MHz ultrasonography in measuring peri-implant osseous destruction was questionable, particularly in presence of prostheses or significant deposits of calculus. Nevertheless, when ultrasonography could be used to measure bone loss, the values reported were generally less than those produced by direct visual measurements (mean difference of −0.1–0.6 mm) [110].

Use of ultrasonography in restorative dentistry

One study compared A-mode ultrasonography with direct visual observation in identifying carious lesions in 47 patients [114]. High diagnostic values were noted (sensitivity, 82%; specificity, 75%; inter-observer agreement, 0.78). It should be noted that 13 carious lesions were removed from the analyses due to it not being possible to classify these particular anomalies as being either carious or not carious even following additional clinical examination (Supplement 3).

Use of ultrasonography in local anesthesia

Three studies (Table 2) compared the anesthesia success of 5–13 MHz ultrasonography-guided versus landmark-guided inferior alveolar [115] or Vazirani-Akinosi nerve block [116]. The studied populations were those in need of regular dental anesthetic injections [115], with acute pain and trismus [116], and prior to mandibular fracture surgeries [117]. The studies reported equal-to-slightly-better anesthetic success rates (two teeth) [115, 116], reduced morphine consumption (1.4 mg less, $p < 0.0001$), and reduced postoperative doses of morphine (7 less within 24 h of fracture surgeries, $p = 0.037$) [117].

Ultrasonic tools

In periodontics, ultrasonic scalers were acknowledged as an alternative to hand scalers by 1960 [118] due to indications of increased efficacy, reduced operator fatigue, and the faster removal of calculus [119]. It is widely thought that there is no difference between ultrasonic and manual debridement in terms of probing depth, reduction of bleeding on probing, plaque and calculus, endotoxin removal, or patient acceptance [120, 121]. However, a large, recent meta-analysis found that manual scaling was superior to ultrasonic scaling in reducing pocket and clinical attachment ≥ 6 mm [122, 123].

In endodontics, ultrasonic waves are transmitted via a file to stream and cavitate (distortion of bubbles) an irrigant, namely an ultrasonic-activated irrigation [124]. There is evidence that ultrasonic-activated irrigations can result in better disinfection and less incidence of pain occurrence within 24 h post instrumentation as compared to conventional irrigation [125, 126]. However, recent meta-analysis found low-quality evidence stating that bacterial presence was the same between passive ultrasonic and conventional irrigation [127]. There is also no significant difference between ultrasonic and syringe irrigation in radiographic healing of the apical periodontitis [127]. Another endodontic application was in instrumentation. Primary studies on the topic [128] find that ultrasonic preparation had a success rate of 94–97% [129–131] but did not have a significant advantage over rotatory files in the removal of inter canal medications [132]. When used to remove broken files, it was found that ultrasonics did not change the rate of healing [133]. Ultrasonics is now routinely used for endodontic microsurgeries using coated diamond tips adapted to conventional ultrasonic devices [134]. As compared to traditional apical surgery with the use of bur, ultrasonic-assisted apical microsurgery was judged to be slower than classical root-end preparation (40 vs. 20 min, respectively) but better in post-surgery pain experience (i.e., faster pain resolution and less analgesic intake) [135, 136] and success rate (81–91% vs. 44–71%) [129–131].

Regarding surgical applications, ultrasonic piezosurgery tools are three times as powerful as conventional ultrasonic scalers [137] and selectively cut mineralized tissue without damaging soft tissues [134]. Their application in osteotomies of the mandible [138] and surgical exposure of impacted canines [8] resulted in a nearly blood-free surgical site with perfect visibility during the osteotomy [138] and reduced procedure time for surgical canine exposure [8]. When used in the enucleation of radicular cysts, piezosurgery was better than conventional surgery in reducing iatrogenic damage and recurrence while increasing operating visibility [137]. A meta-analysis by Jordi et al. found statistically significant fewer perforations of the Schneiderian membrane than with conventional approaches [139]. Additionally, a meta-analysis [140] and various primary studies [135, 136] assessing implant site preparation using piezosurgery found that ultrasonics are alternatives to traditional drilling techniques but have a longer operating time than conventional techniques.

Discussion

Despite the potential therapeutic, interventional, and diagnostic applications of ultrasonography and ultrasound in dentistry, we found that the clinical evidence for their validity and effectiveness is still limited and sometimes contradictory or inconclusive.

The included studies are mostly diagnostic, and a deficiency exists in therapeutic and interventional studies. A general limitation of ultrasonography is that without an acoustic window, it cannot detect objects within the bone, limiting its diagnostic and interventional abilities to soft tissue and intraosseous lesions with thin or no cortical bone, such as the anterior maxillary and mandibular regions. This limitation was suggested, perhaps inadvertently, by the tendency for more dental imaging studies having been performed on anterior teeth [15, 34, 35, 37–39]. For therapeutic ultrasound, there are certain limitations that may cause some hurdles. Therapeutic ultrasound is administered over a long period (typically months), which may add a complicating factor of patient compliance in the clinical applications of this technology. In addition, the range of therapeutic ultrasound intensity is quite large (0.3–1.5 W/cm^2), which is problematic when trying to recommend a specific treatment protocol.

This review has some limitations. Our scoping review only summarized English language studies. We also did not critically appraise included studies due to the accepted framework of scoping reviews [24]. Our extrapolated data was also limited to the defining aspects of the included studies. This was done to give the readers a grasp of the studied scenarios, utilized systems, and clinical applications at the cost of a detailed review of each included study. Our inclusion criteria and target studies are of a heterogeneous nature; therefore, each individual study's methodology and result reporting are varied, which may have resulted in some misclassifications. That said, this study is strong as it was carefully designed following the PRISMA-ScR, with a highly sensitive and comprehensive search and a bibliographic analysis.

The limitations of ultrasonography and ultrasound are notable and should be considered in clinical application and in conducting further research. To correctly administer ultrasound therapy or interpret ultrasonography procedures in daily clinical application, the administrators should receive theoretical, practical, and didactic musculoskeletal ultrasonography courses. It should be noted that the linear array ultrasonography probes are not designed for an intraoral application. Recently, finger-sized probes (e.g., SonicEye® System) [141] have been developed and may be better suited in future research in dentistry (e.g., oral cysts, cancers, fibrous tumors, myofascial trigger points, or embedded foreign objects).

Conclusion

The present scoping review suggests that there could be a broad and multi-use role for diagnostic and interventional ultrasonography or therapeutic ultrasound in dentistry, particularly in endodontics, oral medicine, orthodontics, and surgery; however, more study is required.

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