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Investigating the Role of Ultrasound in the Diagnosis of Oral Lesions: A Scoping Review

Camila Pacheco-Pereira | Sheryn Villarey | Swarna Yerebairapura Math | Konrad Lehmann | Carlos Alberto Figueredo | Fabiana T. Almeida

Mike Petryk School of Dentistry, Faculty of Medicine and Dentistry, University of Alberta, Edmonton, Alberta, Canada

Correspondence: Fabiana T. Almeida (fabiana@ualberta.ca)

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ABSTRACT

Aim: To provide an overview of the diagnostic potential of Ultrasound to assess oral lesions using Magnetic Resonance Imaging, Computed Tomography/Cone-beam computed tomography, or histopathology as the reference standard.

Methods: A literature search was conducted from the following databases: OVID Medline and Embase, Web of Science, Pubmed, and Scopus. The Joanna Briggs Institute Checklist for Systematic Reviews and Research Syntheses tool was used to assess the risk of bias.

Results: Thirty-four studies were included. One study assessed soft tissue lesions, one study assessed intraosseous lesions, and 32 studies assessed malignancies. Ultrasound demonstrated its ability to recognize biomarkers of a diverse range of soft tissue lesions with sensitivity and specificity over 90%. Sensitivity and specificity over 90% were also found for the detection of ameloblastoma proliferation. From studies investigating malignancies, 32% measured the depth of invasion, and 56% measured tumor thickness. The main method of analysis was correlation in 68% of the studies, followed by 25% of the studies assessing sensitivity and specificity.

Conclusion: Ultrasound has the potential to provide accurate information on the characteristics of benign oral lesions and malignancies. It can be used as an initial method of assessment or screening to aid in diagnosis and treatment planning.

1 | Introduction

The presentation of oral and maxillofacial lesions encompasses a wide spectrum of clinical, radiological, and histological features. According to the new 2022 World Health Organization (WHO) classification of head and neck tumors, lesions in the oral cavity and tongue are divided into non-neoplastic (or benign), epithelial tumors, and tumors of uncertain histogenesis (Vered and Wright 2022, Muller and Tilakaratne 2022, Skálová et al. 2022). This diversity necessitates a comprehensive diagnosis approach that integrates clinical examination, imaging, and histopathology examination to ensure proper diagnosis and effective treatment planning (Kumar et al. 2025).

General dentists and specialists have access to a wide range of dental imaging modalities to enhance their diagnosis. Conventional two-dimensional (2D) radiographs are often used as the initial imaging tool to gain information about a lesion's key features and location. While important in the initial diagnostic protocol, they are limited by a lack of three-dimensional (3D) visualization (Suomalainen et al. 2015), imposing distortions and superimposition of adjacent structures around the lesion area, no visualization of soft tissue, affecting the clinician's interpretation and decision-making process (Antony et al. 2020; Korostoff et al. 2016). As a result, a more comprehensive form of assessment with advanced imaging modalities is often needed to provide more diagnostic information to clinicians. These include computed tomography

(CT), cone-beam computed tomography (CBCT), and magnetic resonance imaging (MRI). CT has the key advantage of providing high-resolution imaging of both hard and soft tissues; however, it involves the highest doses of ionizing radiation among options and falls outside the scope of practice or requisition for most dentists (Bos et al. 2023; "Safety and Protection," 2014; Wathen et al. 2013). CBCT provides high-resolution hard tissue imaging with a lower radiation dose than CT but with poor soft tissue contrast (Bos et al. 2023; Kumar et al. 2025; "Safety and Protection," 2014). On the other hand, MRI can provide a great soft tissue contrast and is radiation-free but is limited by high costs and availability (Demirturk Kocasarac et al. 2018). The strengths and limitations of these imaging modalities underscore the need to explore alternatives for faster imaging assessments while minimizing ionizing radiation exposure.

Ultrasound (US) is a noninvasive imaging modality that offers benefits to clinicians, such as low cost, portability, and real-time imaging without ionizing radiation (Demirturk Kocasarac and Angelopoulos 2018). It utilizes electrical energy to produce sound waves that are reflected differently across tissues, creating real-time B-mode images (Shriki 2014). Doppler US extends B-mode imaging by enabling vascularity visualization, as seen in lesions like hemangiomas (Derindağ et al. 2021; Rossler et al. 2011) and malignant soft tissue tumors (Yamamoto et al. 2016) and intraosseous lesions (Sumer et al. 2009).

Studies have increasingly explored the diagnostic capabilities of the US to assess both soft and hard tissues in dentistry, suggesting that US could serve as a useful chairside imaging screening modality for dentists (Almeida et al. 2019; Figueredo, Catunda, et al. 2024; Figueredo, Lai, et al. 2024). Evidence supports its utility in a range of oral lesions, including the assessment of salivary gland lesions and the evaluation of cervical lymph nodes, cystic vs. solid lesions, to assist in the diagnosis of periapical lesions and periodontal status, and to provide complementary information of oral potentially malignant disorders and oral cancers for the decision of further imaging investigation and procedures (Klein Nulent et al. 2018; Ramsubeik et al. 2020). While previous reviews have provided insights into some of these applications (Musu et al. 2016; Patil et al. 2021; Tarabichi et al. 2019), they tended to focus on specific conditions or narrow diagnostic contexts/approaches. Given the rapid advancements of US imaging technology in recent years, there is a clear need for a broader synthesis that maps the existing evidence, identifies knowledge gaps, and outlines opportunities for further research. Due to the heterogeneity of clinical applications and study designs in the current literature, a scoping review methodology was selected. The purpose of this scoping review was to provide a comprehensive overview and characterize the diagnostic potential of US in oral lesions while considering MRI, CT, CBCT, or histopathology as the reference standards. Our ultimate goal was to summarize the available literature on the performance of ultrasound and its contribution to the diagnosis process of oral lesions.

2 | Materials and Methods

The reporting of this scoping review followed the Preferred Reporting Items for a Systematic Review and Meta-analysis Extension for Scoping Reviews (PRISMA-ScR) and the JBI Manual for Evidence Synthesis (Tricco et al. 2018; Aromataris et al. 2024). A protocol was prepared and guided all phases of this scoping review.

2.1 | Research Question

The following structured question guided this review: What is the available evidence regarding the diagnostic potential of ultrasound in diagnosing oral lesions in the oral cavity compared to other imaging modalities or histopathology? It is based on the PCC framework (Koufogiannakis and Brettle 2016) in which the following principles were applied: **P** (Population): Patients with oral lesions; **C** (Concept): diagnostic potential of ultrasound to assess oral lesions; **C** (Context): oral lesions in the oral cavity.

2.2 | Eligibility Criteria

Diagnostic studies assessing the applications of US in the diagnosis of non-endodontic lesions in the oral cavity were included. For this study, the oral cavity was defined as the maxillo-mandibular complex, buccal and alveolar mucosa, lips (including up to the vermillion border), the floor of the mouth (including the sublingual and submandibular glands), and the hard and soft palates. Studies including patients of all ages, regardless of medical comorbidities, were considered. Only articles written in English were considered, with no restriction on the year of publication.

The following exclusion criteria were applied: (1) Cleft/lip palate patients and prenatal US; (2) Any studies that include US assessment of endodontic lesions, including but not limited to periapical cysts, periapical granulomas, periapical abscesses as they were previously investigated (Natanasabapathy et al. 2021); (3) US utilized exclusively for tumor staging, evaluating reconstructive surgery, and guiding treatment, as these are considered interventional or exploratory applications; (4) US in salivary glands and areas other than the oral cavity as they were recently explored (Ramsubeik et al. 2020; Rogalska et al. 2022); (5) US of venous-vascular malformation or phlebolith as as these are anatomical variations rather than pathological lesions; (6) Studies lacking proper reference standard, or reliability analyses; (7) Scoping and systematic reviews, literature reviews, letters, personal opinions, technical notes, book chapters, conference abstracts, unpublished theses, anecdotes, any in vitro and in vivo animal studies, case reports, case series were not considered.

2.3 | Information Sources and Search Strategy

With the assistance of an expert librarian, search strategies for the following electronic databases were performed: OVID Medline, OVID Embase, Web of Science (All Databases), Pubmed, and Scopus. Google Scholar was used for a partial gray literature search for the first 100 results (filtered by "relevance"). For all databases, the end search date was June 20,

2025. Full search queries for each database can be found in Appendix S1.

2.4 | Study Selection and Data Extraction

After searches were performed, all identified citations were exported to Covidence software, available at https://www.covidence.org/home, in which duplicates were automatically removed and cross-checked by two reviewers (SV, SY). This software was also used to streamline the selection process, in which each reviewer independently made a selection decision using this tool. The selection process was completed by two reviewers independently (SV, SY) after calibration with review experts (FTA and CPP). In the first phase, titles and abstracts of articles were reviewed with the inclusion criteria as a basis for which articles could be considered for a full readthrough. In the second phase, the full text of those studies screened successfully in the first step was analyzed independently by the two reviewers (SV, SY), allowing us to further eliminate studies that did not meet our inclusion criteria. Any disagreements were resolved by consensus, with consultation by FTA and CPP as needed. A structured data extraction table was employed to collect the study and sample characteristics, intervention characteristics, and main outcomes.

2.5 | Data Items and Measures

Diagnostic performance was assessed using sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), overall accuracy, and Interclass Correlation Coefficient (ICC) for agreement and consistency. These measures provided a comprehensive evaluation of the reliability and clinical utility of the US in detecting oral lesions.

2.6 | Risk of Bias (RoB) Assessment

A critical appraisal of the potential risk of bias among the individual studies was performed to improve the understanding of their methodological limitations. The RoB assessment was conducted independently by four reviewers (SV, SY) after calibration with a systematic review expert (FTA). Disagreements were solved by a third reviewer (FTA). The Joanna Briggs Institute Checklist for Systematic Reviews and Research Syntheses tool for cross-sectional and cohort studies (JBI's Tools Assess Trust, Relevance, and Results of Published Papers: Enhancing Evidence Synthesis, n.d.) was used for this assessment. Each study was analyzed for several qualities of study design, yielding answers of "yes", "no", "unclear", or "not applicable".

2.7 | Synthesis of Results

The included studies were grouped into benign and malignant tumors. For malignancies, the US ability to assess depth of invasion, tumor thickness, and specific malignancy features was synthesized. The data were analyzed and reported using text and tables, presenting a descriptive summary of study characteristics and main results.

3 | Results

3.1 | Study Selection

The identification, preliminary screening, and inclusion and exclusion of studies are provided in Figure 1. There were 3512 studies screened in phase 1 and 166 studies assessed for eligibility in phase 2. A total of 34 studies were included in this scoping review.

3.2 | Characteristics of Included Studies

The included studies were published from 1989 to 2024 as per a biometric analysis in Figure 2. Benign soft tissue lesions were assessed by one study (Izzetti et al. 2020), benign intraosseous lesions were assessed by one study (Lu et al. 2009), and malignancies were assessed in 32 studies. Thirty-three studies were cross-sectional design (Angelelli et al. 2017; Brouwer De Koning et al. 2019; Bulbul et al. 2021; Caprioli et al. 2022; Chammas et al. 2011; Choi et al. 2015; Cocker et al. 2021; Faraji et al. 2018; Iida et al. 2018; Izzetti et al. 2020, 2021; Kaltoft et al. 2024; Kodama et al. 2010; Konishi et al. 2021; Kumar et al. 2024; Kurokawa et al. 2005; Lodder et al. 2011; Lu et al. 2009; Markovic-Vasiljkovic et al. 2023; Millesi et al. 1990; Natori et al. 2008; Nilsson et al. 2022; Noorlag et al. 2020; Ogura et al. 2013; Rocchetti et al. 2021; Shintani et al. 2001; Smiley et al. 2019; Songra et al. 2006; Takamura et al. 2022; Takashima et al. 1989; Yesuratnam et al. 2014; Yoon et al. 2020, 2021; Yuen et al. 2008). Most studies used gray-scale or B-mode US with frequencies ranging between 5 and 17 MHz. Two studies utilized ultra-high frequency ultrasound (UHFUS) with 70 MHz (Izzetti et al. 2020, 2021) and two studies also explored Power Doppler US for vascularity analysis of the lesions (Lu et al. 2009; Ogura et al. 2013).

As per location and type of lesions, most assessments occurred in tongue lesions, followed by malignancies in the floor of the mouth, buccal mucosa, palate, lip, alveolar mucosa, retromolar trigone, and mandible. These assessments were conducted across various US modalities and for multiple diagnostic indications. The information of included studies is summarized in Table 1.

3.3 | Results of Individual Studies

To facilitate the presentation of the results in this section, the studies were grouped as follows: (1) studies assessing benign or premalignant soft tissue lesions; (2) studies assessing benign intraosseous lesions; (3) studies assessing malignancies.

3.3.1 | Benign or Premalignant Soft Tissue Lesions

The study of Izzetti et al. (2020) described the diagnostic capabilities of the US in non-cancerous oral soft tissue lesions. It included a large sample of benign or premalignant lesions ($n = 142$) and a 70 MHz UHFUS to assess lesion growth pattern, echogenicity, mucosal thickness, and vascularization. The lesions were categorized as autoimmune disease (lichen planus), mucosal growths (traumatic fibromas, fibrous epulis, mucoceles, and HPV papillomas), and oral potentially malignant disorders (OPMD) (such

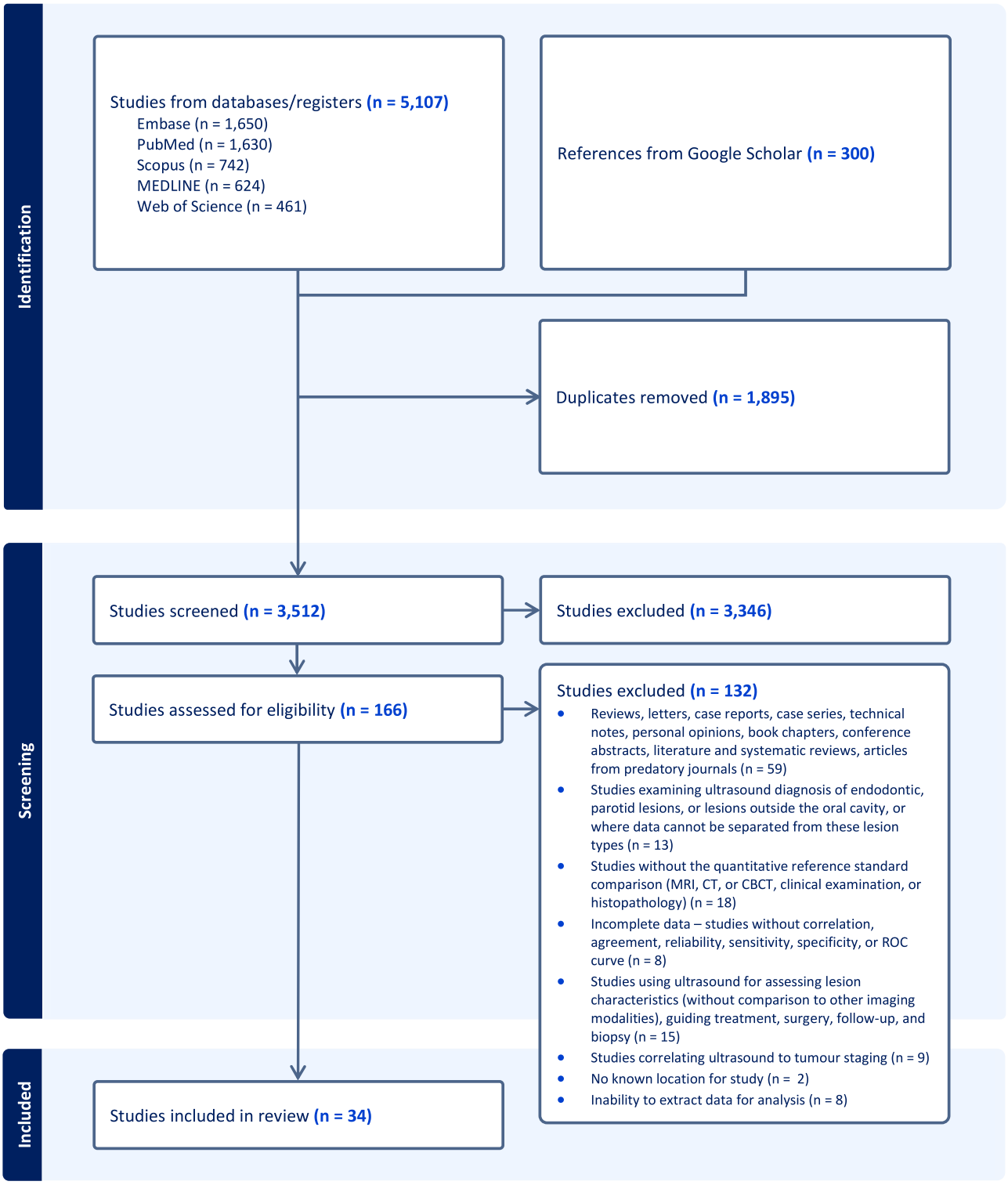

FIGURE 1 | Flow diagram of the search and selection process.

as leukoplakia and erythroplakia). When comparing diagnoses provided with histopathology as the gold standard, UHFUS displayed sensitivity (autoimmune diseases: 91%, mucosal growths: 100%, potentially malignant lesions: 93%) and specificity (autoimmune disease: 98%, mucosal growths: 98%, OPMD: 97%) values above 90% for all soft lesions assessed. The positive predictive value (PPV) was above 95% for both the autoimmune disease (97%) and the mucosal growths (99%) but much lower for OPMD (83%). This same trend was observed in the negative predictive value (NPV), where autoimmune diseases (98%) and mucosal growths (100%) had higher values compared to OPMD (88%).

3.3.2 | Benign Intraosseous Lesions

One study assessing benign intraosseous lesions investigated US capabilities in screening mandibular ameloblastomas (Lu et al. 2009). Color Doppler Flow Imaging (CDFI) was used to

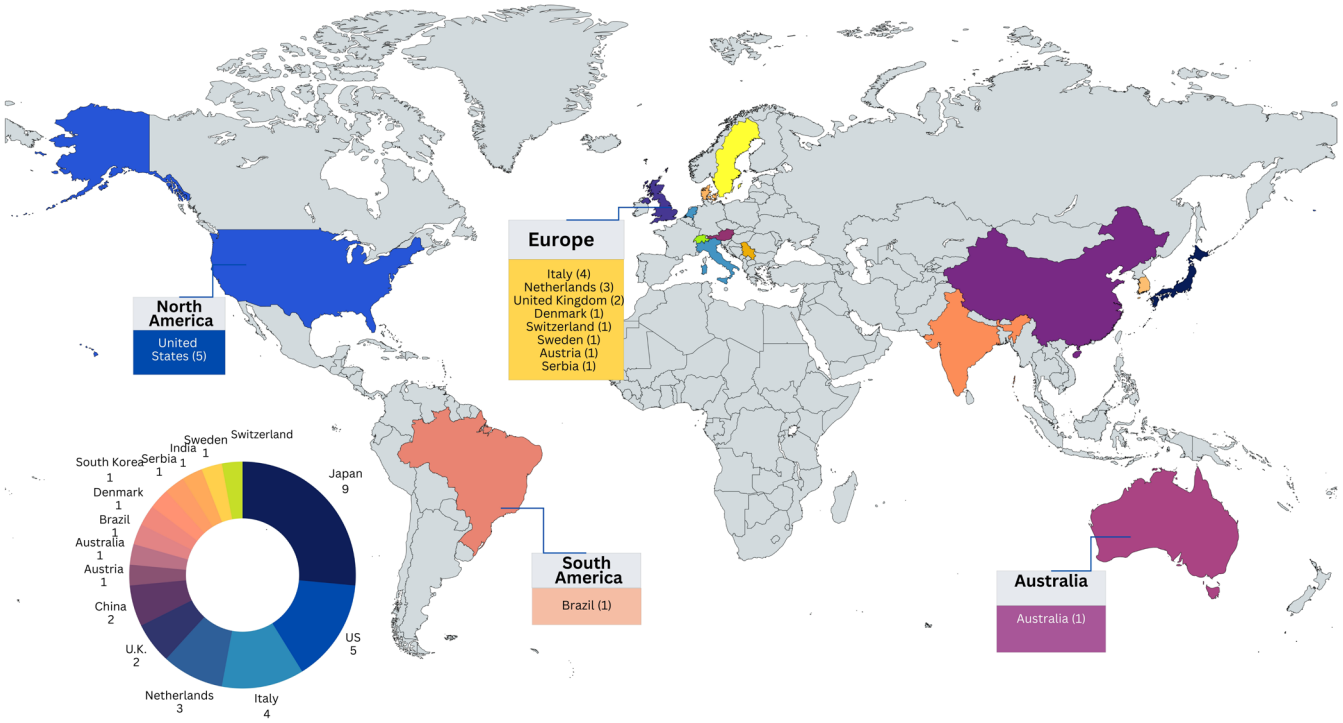

FIGURE 2 | Geographical distribution of included studies.

predict tumor proliferation by analyzing blood flow signals. The authors also predicted these proliferations from the destruction profile of the surrounding bony cortex using gray-scale B-mode US. The US showed a sensitivity of 100% for both indications. However, it was more specific in detecting active tumor proliferations (94%) than in predicting the lesion from cortical destruction (88%).

3.3.3 | Malignancies

3.3.3.1 | Tumor Thickness (TT). Eighteen studies assessed the relationship between TT, determined by different modalities, and histopathological TT (Angelelli et al. 2017; Brouwer De Koning et al. 2019; Chammas et al. 2011; Choi et al. 2015; Izzetti et al. 2021; Kodama et al. 2010; Konishi et al. 2021; Kurokawa et al. 2005; Lodder et al. 2011; Natori et al. 2008; Noorlag et al. 2020; Shintani et al. 2001; Smiley et al. 2019; Songra et al. 2006; Yesuratnam et al. 2014; Yoon et al. 2020, 2021; Yuen et al. 2008). Of these, 10 studies assessed the ability of the US alone to estimate histopathological TT values, with seven studies finding strong correlation values for US derived TT (Kodama et al. 2010; Konishi et al. 2021; Chammas et al. 2011; Yuen et al. 2008; Songra et al. 2006; Izzetti et al. 2021; Yoon et al. 2020). Natori et al. (2008) reported a significant correlation between US and histopathologic TT ($p < 0.001$). Angelelli et al. (2017) evaluated the level of infiltration using TT, concluding that US demonstrated a 91% sensitivity (SN), 100% specificity (SP), PPV of 100%, and NPV of 83%. Choi et al. (2015) compared US-derived preoperative measurements with postoperative histopathologic measurements and supported the predictability of US to measure tongue tumor size (width = 0.91, thickness = 0.97, anterior–posterior dimension = 0.90). Five studies compared the correlation between MRI and US-derived measurements with histopathological TT (Brouwer De Koning et al. 2019; Lodder et al. 2011; Noorlag et al. 2020; Smiley et al. 2019; Yesuratnam et al. 2014). Three of these studies were in agreement that US correlated better than MRI with histopathological measurements (Brouwer De Koning et al. 2019; Lodder et al. 2011; Yesuratnam et al. 2014), however, a large degree of heterogeneity was observed with respect to the range of values of correlation coefficients (US: 0.87 (Lodder et al. 2011)—0.67 (Brouwer De Koning et al. 2019); MRI: 0.69 (Yesuratnam et al. 2014)—0.38 (Brouwer De Koning et al. 2019)). Smiley et al. (2019) reported no difference in accuracy between US (0.48) and MRI (0.40), and Noorlag et al. (2020) reported that both modalities performed equally (US: 0.78; MRI: 0.72). One study comparing the correlation of US and CT derived TT to histopathology supported the superiority of US to CT (US: 0.93; CT: 0.10) (Yoon et al. 2021). Two studies were identified comparing US, CT, and MRI with histopathological TT, with both studies supporting strong correlation values of US compared to CT and MRI (US: 0.98, CT: 0.97, MRI: 0.91 (Shintani et al. 2001); US: 0.97, CT: 0.82, MRI: 0.77 (Kurokawa et al. 2005)).

US-derived TT was found to be strongly correlated with histopathological examination TT (Chammas et al. 2011; Izzetti et al. 2021; Kodama et al. 2010; Konishi et al. 2021; Songra et al. 2006; Yoon et al. 2020; Yuen et al. 2008), however, the varying degrees of heterogeneity in correlation values should be noted. Several studies suggested that US performs better than CT (Kurokawa et al. 2005; Shintani et al. 2001; Yoon et al. 2021) and MRI (Brouwer De Koning et al. 2019; Kurokawa et al. 2005; Lodder et al. 2011; Noorlag et al. 2020; Shintani et al. 2001; Smiley et al. 2019; Yesuratnam et al. 2014) in the evaluation of TT, while two studies reported that US performed equally to MRI (Noorlag et al. 2020; Smiley et al. 2019). One study further investigated the use of US to measure lesions in various

TABLE 1 | Summary of descriptive characteristics of studies in included articles.

Study characteristics	Sample characteristics			Intervention characteristics						Outcome characteristics	
Author, year, country	**Study design**	**Sample size**	**Age range and/or mean (years)**	**Purpose of the imaging**	**Frequency and transducer model**	**Area of interest**	**Imaging mode**	**Reference standard**	**Outcome measures/ analysis**	**Main results**	**Conclusion**
Benign or premalignant soft tissue lesions											
Izzetti et al. (2020) Italy	Cross-sectional	160 (70 M; 90F)	62.92 years	To describe the intraoral application of ultra-high-frequency ultrasonography (UHFUS) in diagnosing oral soft tissue lesions	70 MHz (Vevo MD; VisualSonics)	Oral cavity	UHFUS	Histopathology (HP)	SN, SP, PPV, NPV (order of values in "main results" column) to diagnose autoimmune disease/mucosal growth/potentially premalignant/ and malignancies	Autoimmune disease $n = 35$ (91%/98%/ 97%/98%) Mucosal growths $n = 88$(100%/98%/ 99%/100%) Premalignant lesions $n = 19$ (93%, 97%, 83%, 99%) Malignancies $n = 18$ (100%/98%/88%/ 100%)	Intraoral UHFUS is an effective diagnostic tool in the discrimination and categorization of different oral lesions
Benign intra-osseous lesions											
Lu et al. (2009) China	Cross-sectional	19 (10 M; 9F)	15–61 years (mean 37.8 years)	To assess the potential role of the US in the diagnosis of ameloblastomas	10–13-MHz (LOGIQ 700, GE Healthcare); 3.5–7.5 MHz for large tumors	Mandible	B-mode and CFDI for vascularity analysis	HP	SN and SP: in detecting active tumor proliferations Predicting cortical bone destruction noted with US	SN (100%) and SP (94%) for detecting active tumor proliferations SN (100%) and SP (88%) in predicting cortical bone destruction	Ameloblastomas could be depicted with US blood flow signals on color doppler. The severe destruction of ameloblastomas with increased blood flow signal on Doppler indicates active tumor proliferation and should be treated more aggressively

(Continues)

TABLE 1 | (Continued)

Study characteristics	Sample characteristics			Intervention characteristics					Outcome characteristics	
Author, year, country	**Study design**	**Sample size**	**Age range and/or mean (years)**	**Purpose of the imaging**	**Frequency and transducer model**	**Area of interest**	**Imaging mode**	**Reference standard**	**Outcome measures/ analysis**	**Main results**	**Conclusion**
Malignancies											
Markovic-Vasiljkovic et al. (2023) Serbia	Cross sectional	11 (7 M; 4F)	45–67 years (mean 57.64 years)	To determine the DOI and GD by IOUS and CT methods, and to compare them with HP findings	1012, F-5.5 MHz–10 MHz SonoScape S50 PRO (Guangdong, China)	Tongue and buccal mucosa	B-mode and color Doppler	CT	Pearson's coefficient for correlation between IOUS/CT DOI and GD/HP measures Significance $p < 0.05$ ICC for inter-observer reliability for measurements taken on US and CT	Strong correlation between DOI measured by IOUS and CT with the measurements obtained by HP processing ($p < 0.05$) No correlation with GD values	Measurements of DOI obtained by IOUS significantly correlated with those in the HP report, suggesting that IOUS is a reliable tool in the evaluation of small tumors and tumors that cannot be seen on CT examination. This research emphasizes the role of IOUS in the multimodal diagnostic approach of OCC
Kumar et al. (2024) India	Cross-sectional	50 (37 M; 13F)	mean 47.3 years	To compare different techniques with histopathology in the assessment of DOI	6–13 MHz (SuperSonic Imagine, Aix-en-Provence, France)	Tongue	B-mode	HP	ICC and Cronbach's Alpha	IO-USG was better than CEMRI (ICC: IO-USG: 0.786; CEMRI: 0.689) for predicting DOI	Tongue ultrasound is a reliable imaging modality for assigning accurate T stage
Kaltoft et al. (2024) Denmark	Cross-sectional	30 (18 M; 12F)	40–86 years (mean 69 years)	To compare the accuracy of DOI measurements by intraoral ultrasound and MRI of SCC of the tongue	18 MHz "Hockey Stick" X18L5s and 18 MHz linear 18 L5 or with a 15 MHz Hockey Stick 8809 transducer and 18 MHz linear 8870	Tongue	B-mode	HP	-Bland–Altman compared mean difference and 95% LOA for US and MRI -Wilcoxon signed-rank used to test significance -Correlation evaluated by Pearson's correlation coef	DOI measurements led to a correct T-stage classification in 26 (86.7%) and 17 (56.7%), for intraoral US and MRI, respectively ($p = 0.015$)	IOUS provides a more accurate preoperative assessment of DOI than MRI and can significantly improve the clinical T-staging of oral tongue squamous cell carcinoma

(Continues)

TABLE 1 | (Continued)

Study characteristics	Sample characteristics			Intervention characteristics						Outcome characteristics	
Author, year, country	**Study design**	**Sample size**	**Age range and/or mean (years)**	**Purpose of the imaging**	**Frequency and transducer model**	**Area of interest**	**Imaging mode**	**Reference standard**	**Outcome measures/ analysis**	**Main results**	**Conclusion**
Caprioli et al. (2022) Switzerland	Cross-sectional	41 (25 M;16F)	Mean 64 years	Investigated IOUS to predict the pDOI and T stage in oral tongue SCC, to predict a pDOI > 4 mm	22–8 MHz 8 mm footprint hockey-stick probe Hockey stick 15–7 MHz probe (patients scanned before 2018)	Tongue	B-mode	HP	Bland–Altman between pDOI, usDOI, and mriDOI SP, SN, and ROC curve to determine the ability of IOUS to predict a pDOI less than or equal to 4 mm	SN (100%), SP (94.7%), NPV (60%), and PPV (100%) for IOUS to predict invasive cancer. The area under the ROC curve was 0.8 (95% CI 0.646–0.908, $p < 0.0001$)	-IOUS might be indicated for the local staging of early clinical N0 oral lesions: in this case, the precision in estimating the DOI would have a greater clinical impact in estimating the risk of occult lymph node metastases. -MRI to be proposed for more advanced lesions or if suspicious or enlarged lymph nodes
Nilsson et al. (2022) Sweden	Cross-sectional	40 (25 M;15F)	34–86 years (mean 65 years)	To determine whether DOI can be accurately assessed preoperatively using US (US-DOI) when histopathology (H-DOI) is the gold standard	18 MHz A BKMedical Flex Focus 500 US system (Peabody, MA, USA)	Tongue	B-mode	HP	Bland–Altman plots to compare the agreement of DOI measurements with histopathology	Mean difference for US-DOI compared to H-DOI was −0.5 mm (95% CI 1.2–0.3) with 95% LOA of 4.0 to −4.9 Pearson correlation of mean difference versus mean of US-DOI and H-DOI was −0.6 ($p < 0.001$) MRI-DOI overestimated DOI by 3.9 mm (95% CI 2.7–5.1, $p < 0.001$) compared to H-DOI, with 95% LOA of 2.3–10.2	-Palpation together with US better determines DOI in cT1–T2 tumors compared to MRI. -MRI seems to be more indicated for T3 tumors.

(Continues)

TABLE 1 | (Continued)

Study characteristics	Sample characteristics			Intervention characteristics						Outcome characteristics	
Author, year, country	**Study design**	**Sample size**	**Age range and/or mean (years)**	**Purpose of the imaging**	**Frequency and transducer model**	**Area of interest**	**Imaging mode**	**Reference standard**	**Outcome measures/ analysis**	**Main results**	**Conclusion**
Ogura et al. (2013) Japan	Cross-sectional	48 (27 M; 21F)	7–86 years (mean 52.5 years)	To evaluate the characteristic power Doppler sonographic images of buccal space tumorous and non-tumorous lesions	12-MHz linear transducer (NEMIO 30 SSA-550A; Toshiba Medical Systems)	Buccal space	B-mode and Power Doppler for vascularity analysis	Inter-rater reliability analyses between radiologists ($n=2$)	Reliability (Kappa coef κ) for assessment of lesion boundaries, echogenicity, internal architecture, and vascularity	κ values: 0.76 – boundaries; 0.81 echogenicity; 0.74—internal architecture; 1.00—vascularity	Power Doppler sonography can be a useful technique for the differential diagnosis of buccal space tumors
Natori et al. (2008) Japan	Cross-sectional	110 (sex NA)	NA	To assess IOUS to predict neck metastasis and delineate the extent of tumor	7.5-MHz I-shaped or T-shaped linear transducer (SSD1200CV; ALOKA Co. LTD.)	Tongue	B-mode	HP (for TT) and MRI (for detection rate)	Correlative study using linear regression analysis	Detection rates based on T-stage (US vs. MRI): T1: 72.5% vs. 45.2%; T2: 96.5% vs. 80.4%; T3 and T4: 100% vs. 100% Detection rate according to growth pattern (US vs. MRI): Superficial: 57.1% vs. 10.0%; Endophytic: 100% vs. 93.1%; Exophytic: 95.7% vs. 72.7% All lesions over 1 mm TT detected by US; most lesions less than 5.0 mm not detected by MRI Overall detection rate of primary tongue lesions: 88.2% by US vs. 72.0% by MRI Significant correlations ($R=0.74$; $p<0.001$) between TT measured by US and histopathology US-TT: 13% over-assessment compared to surgical section	IOUS assessment of the tumor thickness and the pattern of tumor margins provide useful information to perform optimal treatment based on the grade of malignancy for patients with tongue cancer, particularly early-stage tumor

(Continues)

TABLE 1 | (Continued)

Study characteristics	Sample characteristics			Intervention characteristics						Outcome characteristics	
Author, year, country	**Study design**	**Sample size**	**Age range and/or mean (years)**	**Purpose of the imaging**	**Frequency and transducer model**	**Area of interest**	**Imaging mode**	**Reference standard**	**Outcome measures/ analysis**	**Main results**	**Conclusion**
Kodama et al. (2010) Japan	Cross-sectional	13 (8 M; 5 F)	38–87 years (mean 61.6 years)	To evaluate the correlation between tumor thickness shown by ultrasonographic and histologic results	7.5-MHz sector probe (SSD-1200CV; ALOKA)	Tongue	B-mode	HP	Correlation study using Pearson's correlation coefficient (r)	US-measured TT is significantly correlated with TT determined from histopathological analysis ($r = 0.981$, $p < 0.05$).	Intraoral intraoperative ultrasonography was found to be an accurate and reliable tool for assessing tumor thickness and surgical clearance in tongue carcinomas
Lodder et al. (2011) Netherlands	Cross-sectional	65 (34 M; 31F)	42–89 years (mean 65 years)	To investigate TT measurement with an intraoperative US probe	7–15-MHz intraoperative probe ($n = 44$); (Phillips IU-22, L15-7) 5–7-MHz non-dedicated small parts probe (scans prior 2007)	Tongue, floor of mouth, and oral cavity	B-mode	HP	Correlation study using Pearson's correlation coefficient (r)	US and histopathology ($r = 0.87$) MRI and histopathology ($r = 0.54$) 5–7-MHz transducer vs. histopathology ($r = 0.05$) 7–15-MHz transducer vs. histopathology ($r = 0.93$)	US measurement is more reliable than MRI for the measurement of tumor thickness, especially in superficial lesions US seems to be the optimal technique in patients with no limited mouth opening or BOT involvement
Choi et al. (2015) Korea	Cross sectional	29 (22 M; 7F)	26–74 years (mean 52 years)	To evaluate the correlation between preoperative US measurements and postoperative pathology measurements of tongue tumor size	5–12-MHz linear transducer (HDI 5000; Philips)	Tongue	B-mode	HP	Spearman's correlation coefficient (ρ) in three dimensions: 1. Anterior–posterior measurements along the long axis of the tongue; 2. Width—vertical to the long axis of the tongue; 3. Thickness—surface to the midline of the tongue	ρ values: anterior–posterior = 0.905 ($p < 0.001$), width = 0.918 ($p < 0.001$), thickness = 0.971 ($p < 0.001$)	US enables prediction of the extent of tongue tumors. Its measurements correlate with histopathology measurements

(Continues)

TABLE 1 | (Continued)

Study characteristics	Sample characteristics			Intervention characteristics						Outcome characteristics	
Author, year, country	**Study design**	**Sample size**	**Age range and/or mean (years)**	**Purpose of the imaging**	**Frequency and transducer model**	**Area of interest**	**Imaging mode**	**Reference standard**	**Outcome measures/ analysis**	**Main results**	**Conclusion**
Takashima et al. (1989) Japan	Cross-sectional	10 (9M; 1F)	23–72 years (mean 55 years)	To describe the findings of MRI and US and correlate with pathologic findings in patients who have undergone surgery	5-MHz Real-time sector scanner	Tongue	B-mode	HP	SN and SP of US to detect primary tumors, to assess expansion over the midline, and to assess spread outside of the tongue region	Detecting primary tumors (US vs. MRI): SN: 85.7% vs. 100%; SP: could not be measured; PPV: 100% for both; NPV: 0% vs. not measured Expansion over midline (US vs. MRI): SN, SP, PPV, NPV: 100% for both Tumor spread outside tongue (US vs. MRI): SN: 33.3% vs. 100%; SP: 100% vs. 75%; PPV: 100% vs. 75% NPV: 66.7% vs. 100%	MR and US have almost the same SN for detecting primary-site tongue cancer. MRI is superior to US in the evaluation of extra-organ spread of tumor
Bulbul et al. (2021) USA	Cross-sectional	44 (25M; 19F)	NA (no age restrictions)	To correlate IOUS measurement of DOI to histological measurement	Broadband compact linear array transducer (L15-7io; Philips)	Tongue	B-mode	HP	Correlation study using Pearson's correlation coefficient (r)	IOUS-DOI and HP-DOI ($r = 0.9449$, $p < 0.0001$)	IOUS appears to be a potential tool in guiding OTC resections based on the results of this series, where it accurately measured DOI and improved deep margin clearance and tumor cut through rates over those seen in our control group and that reported in the literature
Shintani et al. (2001) Japan	Cross-sectional	39 (25M; 14F)	36–91 years (mean 58.2 years)	To compare the clinical usefulness of CT, MRI and IOUS to delineate the extent of tumors and to measure the tumor thickness of oral carcinoma	7.5-MHz intracavitary transducers (PEF-704LA, Toshiba, UST-995, UST-5536, Aloka)	Buccal Mucosa, Tongue, Floor of Mouth	B-mode	HP	Correlation study using Pearson's correlation coefficient (r)	$r = 0.988$ vs. 0.976 vs. 0.911 for US, CT, and MRI, respectively, compared to HP	IOUS is very accurate and hence of good value for mapping these tumors

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TABLE 1 | (Continued)

Study characteristics	Sample characteristics			Intervention characteristics						Outcome characteristics	
Author, year, country	**Study design**	**Sample size**	**Age range and/or mean (years)**	**Purpose of the imaging**	**Frequency and transducer model**	**Area of interest**	**Imaging mode**	**Reference standard**	**Outcome measures/ analysis**	**Main results**	**Conclusion**
Brouwer De Koning et al. (2019) Netherlands	Cross-sectional	US: TT ($n=76$) and greatest dimension ($n=44$). MR: TT ($n=46$) and greatest dimension ($n=47$).	31–88 years (mean 61 years)	To compare greatest dimension and tumor thickness measurements from US and MR with... histopathology	13–7-MHz transducer (EUB-900, Hitachi)	Tongue, Floor of Mouth, Palate, and Lip	B-mode	HP	Correlation study using Pearson's correlation coefficient (r) Agreement between US/MR and histopathology using Bland–Altman Plot and a 95% agreement (1.96 x SD)	TT: US vs. histopathology: $r=0.67$, $p<0.001$; MR vs. histopathology: $r=0.38$, $p=0.009$. Mean difference between US and HP TT = 0.05 mm (SD 2.7 mm) with 95% LOA spanning 10.7 mm. Mean difference between MR and HP TT measurements was 1.3 mm (SD 3.7 mm), with 95% LOA spanning 14.7 mm GD: US vs. HP: $r=0.61$, $p<0.001$; MR vs. HP: $r=0.69$, $p<0.001$; Mean difference between US and HP GD = –1.6 mm (SD 6.8 mm), with 95% LOA 26.6 mm. Mean difference between MR and HP GD measurements was 1.1 mm (SD 6.6 mm) with 95% LOA spanning 25.7 mm.	Compared to MR, the tumor thickness measured on US showed a higher correlation and agreement with histopathology Compared to US, the GD measured on MR showed a higher correlation and agreement with histopathology The oral cavity tumor thickness is more accurately measured with US than MR for pre- operative tumor staging

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TABLE 1 | (Continued)

Study characteristics	Sample characteristics			Intervention characteristics						Outcome characteristics	
Author, year, country	**Study design**	**Sample size**	**Age range and/or mean (years)**	**Purpose of the imaging**	**Frequency and transducer model**	**Area of interest**	**Imaging mode**	**Reference standard**	**Outcome measures/ analysis**	**Main results**	**Conclusion**
Konishi et al. (2021) Japan	Cross-sectional	46 (21 M; 25F)	62.1 years ±18.8 years	To investigate the relationships between IOUS and histopathological findings regarding late cervical lymph node metastasis in patients with tongue cancer	38–50 mm linear 7.5-MHz probe (ProSound Alpha 7; Hitachi Aloka Medical).	Tongue	B-mode	HP	Pearson's correlation coefficient (r)	IOUS-TT and HP-TT ($r = 0.84$, $p < 0.0001$, 95% confidence interval (CI): 0.73–0.91)	The thickness measured using intraoral ultrasonography and histopathological analysis showed a statistically significant correlation
Chammas et al. (2011) Brazil	Cross-sectional	19 (11 M; 8 F)	36–79 years (mean 60 years)	Examined the usefulness of IOUS for predicting neck metastasis and delineating the extent of the tumor based on a comparison with the histopathological findings	5–10-MHz 44 mm x 10 mm linear array, with a T-shaped intraoperative transducer No model listed	Tongue	B- mode	HP	Correlation study using Pearson's correlation coefficient (r)	Average thickness measurements: HP: 1.3 cm (range 0.50–3.5 cm); IOUS: 1.6 cm (0.50–3.5 cm); US TT vs. HP TT: $r = 0.83$; $p < 0.001$	IOUS is valuable tool for identifying tongue tumors and measuring their thickness, with the thickness measured by IOUS showing a very good correlation with histological measurements.
Faraji et al. (2018) USA	Cross sectional	24 with HPV-positive carcinoma (sex NA)	26–81 years (mean 60.9 years)	To examine the performance of blinded US readers in identifying human papilloma virus-related oropharyngeal carcinoma from tonsil and BOT	C5-1, C8-5, and X6-1 transducers with the Philips iU22 or Philips EPIQ7 (Koninklijke Philips N.V)	Base of tongue (BOT)	B-mode	Inter-rater reliability	Inter-rater reliability analyses ($n = 6$) with Fleiss' kappa (κ) Accuracy, SN and SP for all 6 raters.	BOT test (median value/ IQR): Accuracy: 79%/76.9%–82.5%/69.2%–84.1%; SN: 73.4%/68.8–77.9/58%–81%; SP: 85%/84.1%–88.5%/81.8%–89.7% Inter-rater reliability: $\kappa = 0.510$; moderate	US has clinically useful SN for the identification of oropharyngeal carcinoma among readers with diverse clinical backgrounds and experience

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TABLE 1 | (Continued)

Study characteristics	Sample characteristics			Intervention characteristics						Outcome characteristics	
Author, year, country	**Study design**	**Sample size**	**Age range and/or mean (years)**	**Purpose of the imaging**	**Frequency and transducer model**	**Area of interest**	**Imaging mode**	**Reference standard**	**Outcome measures/ analysis**	**Main results**	**Conclusion**
Kurokawa et al. (2005) Japan	Cross sectional	28 (18 M; 10F)	27–80 years (mean 59.4 years)	To evaluate the utility of IOUS to assess tongue carcinoma and compare the findings with CT and MRI	7.5-MHz intracavity transducer Model not described	Tongue	B-mode	HP	Correlation study using Spearman rank correlation rest (ρ).	Mean TT: US: 10.5 mm (SD, 8.1 mm); HP: 7.1 mm (SD, 6.3 mm). US TT and HP TT: $\rho = 0.976$; $p < 0.0001$ CT vs. histopathology: $\rho = 0.823$; $p = 0.0018$ MRI vs. histopathology $\rho = 0.778$; $p < 0.0001$	IOUS appears to be more accurate than CT or MRI for the preoperative assessment of tumor thickness in tongue carcinoma
Yuen et al. (2008) China	Cross sectional	45 (28 M; 17F)	22–90 years (mean 59 years)	To evaluate the correlation between ultrasonic and pathologic TT to stage the tumor thickness of oral tongue carcinoma preoperatively	7.5-MHz right-angled probe (SSD-1700; Aloka Ultrasonic System)	Tongue	B-mode	HP	Correlation study using Pearson's correlation coefficient (r)	US TT and HP TT: $r = 0.940$, $p < 0.005$	IOUS provides accurate assessment modality for thickness of oral tongue carcinoma
Rocchetti et al. (2021) Italy	Cross sectional	32 (20 M; 12F)	Males: mean 62.0 years Females: mean 71.2 years	To assess the performance of US in depicting the infiltration of the tumor beyond the lamina propria into the submucosa; assess the correlation of the DOI calculated by using US and measured postoperatively in the histological surgical specimen; and assess the correlation of DOI with tumor diameter measured with US	8–17-MHz "hockey stick" probe and 3–12-MHz linear oral fitting-shaped probe E-CUBE 15 EX US scanner (Alpinion Medical Systems)	Tongue	B-mode and color Doppler US	HP	SN, SP and Pearson's correlation coefficient (r)	Evaluating extension of tumor spread beyond the lamina propria with US: SN: 93.1% SP: 100% PPV: 100% NPV: 60% DOI US vs. HP: $r = 0.907$; $p < 0.001$; 95% CI 0.816–0.954	IOUS can provide useful information to determine the optimal treatment for patients with OSCC, particularly in early-stage tumors

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TABLE 1 | (Continued)

Study characteristics	Sample characteristics			Intervention characteristics						Outcome characteristics	
Author, year, country	**Study design**	**Sample size**	**Age range and/or mean (years)**	**Purpose of the imaging**	**Frequency and transducer model**	**Area of interest**	**Imaging mode**	**Reference standard**	**Outcome measures/ analysis**	**Main results**	**Conclusion**
Yesuratnam et al. (2014) Australia	Cross sectional	88 (47 M; 41 F)	30–91 years (mean 63 years)	To investigate the correlation between TT on US and MRI with the histologically determined TT of tongue cancers	15–7-MHz linear probe with "hockey stick probe" (L15-7io on a Philips iU22; Philips Medical)	Tongue	B-mode	HP	Pearson's correlation coefficient (r) Agreement between US/ MR (both T1 post-contrast and T2-weighted) and histopathology using Bland–Altman Plot	HP vs.: US: $r = 0.80$ (95% CI 0.71–0.87) T1 post-contrast MRI: $r = 0.69$ (95% CI 0.55–0.79) T2-weighted MRI: $r = 0.64$ (95% CI 0.49–0.75) Mean differences between values of HP and US: 1.28 mm (SD 3.55 mm); T1 post-contrast MRI: 2.99 mm (SD 4.41 mm); T2-weighted MRI—3.19 mm (SD 4.87 mm)	High correlation between TT measured on pre-operative US and histological primary TT, and good correlation between MRI and histological primary TT
Songra et al. (2006) United Kingdom	Cross sectional	14 (sex NA)	NA (No age restrictions)	To see if ultrasound can accurately predict whether the surgical margin is involved, compared to histological analysis	5–10-MHz broadband linear Small Parts probe (HDI 5000; Advanced Technologies Ltd.)	Tongue, Alveolar Mucosa, Lip, Floor of Mouth	B-mode	HP	Pearson's correlation coefficient (r) and Spearman's rank correlation coefficient (ρ)	US vs. HP TT: $r = 0.948$, $p < 0.01$; $\rho = 0.913$, $p < 0.01$	US showed a high degree of reliability with histological measurements for tumor thickness High resolution IOUS is a reliable tool in assessing: 1. tumor thickness 2. surgical margin clearance at the time of operation

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TABLE 1 | (Continued)

Study characteristics	Sample characteristics			Intervention characteristics						Outcome characteristics	
Author, year, country	**Study design**	**Sample size**	**Age range and/or mean (years)**	**Purpose of the imaging**	**Frequency and transducer model**	**Area of interest**	**Imaging mode**	**Reference standard**	**Outcome measures/ analysis**	**Main results**	**Conclusion**
Smiley et al. (2019) USA	Cohort Study	10 (7M; 3F)	49–96 years (mean 62.7 years)	To estimate and compare the accuracy of TT measurements using US, MRI, and clinical evaluation in the measurement of OSCC	7–12-MHz "hockey-stick" scan probe intraorally; 7–12 MHz linear transducer extraorally	Tongue, Floor of Mouth, Retromolar Trigone, Mandible	B-mode	HP	Correlation study using Pearson's correlation coefficient (r) Calculation of mean and absolute differences relative to histopathology	-US TT vs. HP TT: $r = 0.4769$; $n = 6$ MRI TT vs. HP TT: $r = 0.4012$; $n = 5$ Clinical assessment TT vs. HP TTt: $r = 0.0924$; $n = 7$ -Mean TT differences: US vs. MRI vs. clinical assessment: −0.33 mm vs. −0.47 mm vs. −0.64 mm ($p = 0.9$; not significant (N.S)) Absolute TT differences: US vs. MRI vs. clinical assessment: 0.93 mm vs. 1.01 mm vs. 0.99 mm ($p = 0.974$)	The accuracy of US does not differ from MRI or clinical assessment of OSCC primary tumor size Underestimating TT was noted as an inherent shortcoming of all imaging modalities
Izzetti et al. (2021) Italy	Cross sectional	10 (4M;6F)	56–83 years (mean 68.7 years)	To evaluate the utility of UHFUS in the assessment of OSCC and to compare DOI and TT values with histology	70-MHz probe (Vevo MD; VisualSonics)	Tongue, Gingiva, Buccal Mucosa, Floor of Mouth	B-mode	HP	Pearson's correlation coefficient (r). Mean difference between UHFUS and histopathology	Correlation for UHFUS with histopathology: TT: $r = 0.9835$, $p < 0.05$; DOI: $r = 0.9631$, $p < 0.05$ for DOI Mean differences: TT: −0.10 mm; DOI: 0.14 mm	UHFUS has the potential to become a valuable technique for the evaluation of OSCC, and give insight into surgical management TT was slightly underestimated on UHFUS while DOI was overestimated

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TABLE 1 | (Continued)

Study characteristics	Sample characteristics			Intervention characteristics						Outcome characteristics	
Author, year, country	**Study design**	**Sample size**	**Age range and/or mean (years)**	**Purpose of the imaging**	**Frequency and transducer model**	**Area of interest**	**Imaging mode**	**Reference standard**	**Outcome measures/ analysis**	**Main results**	**Conclusion**
Angelelli et al. (2017) Italy	Cross Sectional	32 (17 M;15F)	31–63 years	To consider the possibility of assessing with ultrasound the TT in relation to the involved histological layers, and to correlate the level of histological infiltration with the superficial extension and the TT measured in mm	18-MHz intraoperative "hockey stick" shaped probe (GE Logic 9)	Tongue, Buccal Mucosa, Palate, Mandible	B-mode and Color Doppler	HP	SN, SP, Accuracy, PPV, NPV between US and histological level of infiltration	Correlating US and histological level of infiltration: SN—91%; SP—100%; Acuracy—94%, PPV—100% NPV—83%	The use of high-frequency ultrasound transducers (18 MHz) allows the correct assessment of the different layers within the various anatomic structures of the oral cavity
Cocker et al. (2021) United Kingdom	Cross sectional	185 (162 MRI; 40 CT; 84 US) (sex NA)	NA	To establish the accuracy of assessments of tumor DOI by comparing the pre-treatment depths on imaging with the final histopathological tumor depths	5–9-MHz frequency and a 25 mm footprint (General Electric L8-18 "hockey stick" probe)	Floor of Mouth, Hard Palate, Buccal Mucosa, Tongue, Gingival Mucosa	B-mode	HP	Percent accuracy of measurements performed with CT, MRI, and US relative to histopathology Student's t-test to assess the significance of mean differences in DOI measurements between histopathology and US, MRI, and CT	Accuracy testing: US: exact match: 11.5%; ±3 mm: 66.7%; > ±3 mm: 21.8% MRI: exact match: 1%; ±3 mm: 55.8%; > ±3 mm: 43.3% CT: exact match: 4.8%; ±3 mm: 52.4%; > ±3 mm: 42.9% Mean differences between histopathological and radiological DOI: CT vs. MRI—$p = 0.06$; N.S CT vs. US—$p = 0.47$; N.S MRI vs. US—$p < 0.001$	Current imaging protocols may not provide robust and accurate assessment of tumor depth in the oral cavity. The most reliable method found in this study was IOUS

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TABLE 1 | (Continued)

Study characteristics	Sample characteristics			Intervention characteristics						Outcome characteristics	
Author, year, country	**Study design**	**Sample size**	**Age range and/or mean (years)**	**Purpose of the imaging**	**Frequency and transducer model**	**Area of interest**	**Imaging mode**	**Reference standard**	**Outcome measures/ analysis**	**Main results**	**Conclusion**
Millesi et al. (1990) Austria	Cross sectional	31 (22M; 9F)	mean 60.7 years	The results of conventional radiographic examination, CT, US and Tc scanning in detecting tumor invasion of the mandibular bone are documented and correlated to surgical and histological findings	7.5-MHz real-time sector scanner (Ultramark 8, ATL)	Floor of Mouth, Tongue	B-mode	HP	Sensitivity analysis of conventional radiography, CT, and US relative to histopathology	SN: Conventional radiography: 90%; CT: 86%; US: 93%	The imaging techniques for the evaluation of tumors of the floor of the mouth and the tongue not only provide excellent imaging of tumor extension in the soft tissue, but also allow diagnosis of osteodestruction of the mandible. The lingual surface of the mandibular ramus can not be screened by the extraoral sonography
Iida et al. (2018) Japan	Cross sectional	56 (34M;22F)	25–90 years (mean 59 years)	To evaluate the accuracy of the preoperative measurement of DOI using US for superficial oral tongue carcinomas and to correlate preoperative US-DOI with the histologically reported DOI for SCC of the tongue	16-MHz T-shaped probe (UST-5713T/ Intraoperative Electronic Linear Probe; Hitachi Aloka Medical Ltd)	Tongue	B-mode	HP	Spearman's rank correlation coefficient (ρ). SN and SP of US in assessing DOI	US DOI and HP DOI: $\rho = 0.867$; $p < 0.001$ SN: 92.3%; SP: 70.6%	US measurement of the DOI is a reliable diagnostic tool for superficial oral tongue carcinomas (measuring ≤5 mm)
Yoon et al. (2020) USA	Cross sectional	20 (13M;7F)	27–82 years	To determine the accuracy of intraoperative US in assessing TT and DOI of oral tongue SCC, compared with histopathologically assessed TT and DOI	Broadband compact linear array transducer (L15-7io; Philips Healthcare)	Tongue	B-mode and color Doppler	HP	Correlation study using Pearson's correlation coefficient (r)	Correlations between US and histopathology: TT: $r = 0.95$ (95% CI, 0.87–0.98) DOI: $r = 0.95$ (95% CI, 0.87–0.98)	Intraoperative US can provide objective, real-time assessment of TT and DOI with excellent correlation with histologic evaluation

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TABLE 1 | (Continued)

Study characteristics	Sample characteristics			Intervention characteristics						Outcome characteristics	
Author, year, country	**Study design**	**Sample size**	**Age range and/or mean (years)**	**Purpose of the imaging**	**Frequency and transducer model**	**Area of interest**	**Imaging mode**	**Reference standard**	**Outcome measures/ analysis**	**Main results**	**Conclusion**
Yoon et al. (2021) USA	Cross sectional	19 (13M;6F)	27–82 years (mean 59.6 years)	To examine the reliability and accuracy of preoperative CT in assessing TT of SCC with those from intraoperative US and histopathologic assessment	Broadband compact linear array transducer (L15-7io; Philips Healthcare)	Tongue	B-mode and Doppler	HP	Correlation study using Pearson's correlation coefficient (r)	Correlation of TT measurements: CT vs. histopathology: $r = 0.10$ (95% CI: −0.53-0.66) US vs. histopathology: $r = 0.93$ (95% CI: 0.74–0.98).	Preoperative CT was found to be neither accurate nor reliable for assessment of primary SCC tumor thickness, while readily visible and well-defined on US. CT TT has poor correlation with histopathological TT while US TT has excellent correlation with histopathological TT
Noorlag et al. (2020) Netherlands	Cross sectional	146 (74M; 72F) TT measured with MRI in $n = 83$ and US in $n = 107$.	34–87 years (mean 64 years)	To analyze the accuracy of pre-operatively measured TTs by MRI and/or US compared with the histopathological DOIs of the resection specimens of small (cT1–T2) tongue cancers	15 MHz "hockey stick" shaped transducer No model listed	Tongue	B-mode	HP	Correlation study using Pearson's correlation coefficient (r) Mean absolute difference of US and MRI measurements compared to histopathology.	TT correlations with histopathology: MRI: $r = 0.72$; $p < 0.001$; US: $r = 0.78$; $p < 0.001$. Mean absolute differences: DOI 0–10 mm: MRI: 3.1 mm (SD 3.2 mm) US: 1.6 mm (SD 1.3 mm). DOI > 10 mm: MRI: 3.5 mm (SD 3.0 mm); US: 4.7 mm (SD 3.5 mm)	The TT that is measured on both MRI and US for tongue cancers correlates well with histopathological DOI measurements In tumors with a DOI up to 10 mm, US is more accurate than MRI and should be the preferred imaging technique. In thicker tumors, the accuracy of preoperative US measurement drops

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TABLE 1 | (Continued)

Study characteristics	Sample characteristics			Intervention characteristics						Outcome characteristics	
Author, year, country	**Study design**	**Sample size**	**Age range and/or mean (years)**	**Purpose of the imaging**	**Frequency and transducer model**	**Area of interest**	**Imaging mode**	**Reference standard**	**Outcome measures/ analysis**	**Main results**	**Conclusion**
Takamura et al. (2022) Japan	Cross sectional	48 (28M;20F)	23–90years (mean 65.7years)	To assess the accuracy of US, CT, MRI in preoperative image DOI measurement of T1/T2 tongue cancer compared with histopathology	7–13MHz "hockey stick: small transducer EUP-054J (HI VISION Preirus, Hitachi)	Tongue	B mode	HP	Correlation study using Spearman's rank correlation coefficient (ρ). Agreement between US/ MR (both T1 post-contrast and T2-weighted) and histopathology using Bland–Altman Plot	US: Mean difference with histopathology DOI: 0.2mm (SD 1.4mm) with 95% limits of agreement spanning 5.5mm MRI: Mean difference with histopathology DOI (4 separate sections across two MRI imaging techniques): 1.9mm–2.5mm (SD 1.6mm–2.1mm) with 95% limits of agreement spanning 5.8mm–8.2mm CT: Mean difference with histopathology DOI (across two sections): 2.6mm (SD 2.4mm–2.5mm) with 95% limits of agreement spanning 9.5–9.9mm Correlation with histopathology DOI: US: ρ = 0.83 MRI (4 separate sections across two MRI techniques): ρ = 0.66–0.83 CT (across two sections): ρ = 0.58–0.62	US is the most accurate preoperative diagnostic tool for T1 and T2 squamous cell carcinoma; CT and MRI tend to have an overestimation of about 2–3mm and so caution is required. US DOI was overestimated by an average 0.2mm compared to the histopathological DOI

Abbreviations: ϰ, Kappa coefficient; AP, Anterior posterior; BOT, Base of tongue; CDFI, Color doppler flow imaging; CI, Confidence interval; CT, Computed Tomography; DOI, Depth of invasion; F, Female; GD, Greatest diameter; HP, Histopathology; ICC, Intraclass correlation coefficient; IOUS, Intraoral ultrasonography; LOA, Limits of agreement; M, Male; MR(I), Magnetic resonance (imaging); NA, Not available; NPV, Negative predictive value; NS, Not significant; OCC, Oral cavity carcinoma; OSCC, Oral squamous cell carcinoma; PPV, Positive predictive value; SCC, Squamous cell carcinoma; SD, Standard deviation; TH, Thickness; TT, Tumor thickness; UHFUS, Ultra-high-frequency ultrasonography; US, Ultrasonography; WD, Width.

dimensions preoperatively and compared these measurements to postoperative histopathological results. This study demonstrated that US can accurately measure the size of tumors in its width, thickness, and in the anterior–posterior dimension (Natori et al. 2008).

3.3.3.2 | Depth of Invasion (DOI). Several studies measured the US ability to assess DOI compared to histopathological standards with ICC values ranging between 0.83 and 0.96 (Table 1). Kaltoft et al. (2024) concluded that there was a strong correlation between US and histopathological DOI (0.86) and a moderate correlation between MRI and histopathological DOI (0.57), further supporting that the strong correlation between US and histopathological DOI led to more accurate T-staging of tongue squamous cell carcinoma (SCC) (US: 86.7%, MRI: 56.7%). Markovic-Vasiljkovic et al. (2023) showed that both US and CT correlated strongly with histopathology (0.94 and 0.86); however, a weak correlation was found for US and CT when measuring the diameter of the lesions (GD values 0.27 and −0.61). Kumar et al. (2024) reported an ICC of 0.78 for US-DOI compared to histopathology, whereas contrast-enhanced MRI (CEMRI) achieved a coefficient of 0.68. This study further noted that US provides better predictive values for DOI than CEMRI for lesions that are less than or equal to 5 mm. US-measured DOI values overestimated histopathological values in three studies (Izzetti et al. 2021; Noorlag et al. 2020; Takamura et al. 2022), with values between 0.14 mm (Izzetti et al. 2021) and 4.7 mm (Noorlag et al. 2020). Conversely, one study showed that US-measured DOI differed from histopathological-DOI by a mean difference of −0.5 mm. In contrast, the mean difference for MRI-DOI was 3.9 mm, suggesting that MRI-measured DOI tends to be overestimated, particularly in T1–T2 tumors (Nilsson et al. 2022). Noorlag et al. (2020) observed that US overestimated DOI less than MRI for tumors with invasion less than 10 mm, though the trend reversed for tumors with invasion greater than 10 mm. Takamura et al. (2022) compared the estimation potential of US to CT and MRI and found the mean overestimation was lowest with US (0.2 mm) compared to MRI (1.9–2.5 mm) and CT (2.6 mm). Interestingly, as with TT (Brouwer De Koning et al. 2019), the overall spread of DOI measurements around the mean was closer for US (5.5 mm) compared to MRI (5.8–8.2 mm) and CT (9.5–9.9 mm) (Takamura et al. 2022). Three studies assessed sensitivity and specificity of US in evaluating DOI (Caprioli et al. 2022; Iida et al. 2018; Rocchetti et al. 2021), all reporting sensitivity greater than 90%, while specificity ranged from 70.6% (Iida et al. 2018) to 100% (Caprioli et al. 2022; Rocchetti et al. 2021). Cocker et al. (2021) also assessed the accuracy of DOI measurements made by the US and found that a higher proportion of measurements were made within a smaller tolerance thickness than CT and MRI.

US-DOI showed a correlation of 90% with histopathological DOI in multiple studies (Izzetti et al. 2021; Kaltoft et al. 2024; Takamura et al. 2022). US tends to overestimate DOI (Izzetti et al. 2021; Noorlag et al. 2020; Takamura et al. 2022); however, in comparison to MRI and CT, the variance of DOI measurements and mean overestimation were smaller for US (Brouwer De Koning et al. 2019; Nilsson et al. 2022; Takamura et al. 2022). The US also showed 90% sensitivity in measuring DOI and had varying degrees of specificity (Caprioli et al. 2022; Iida et al. 2018; Rocchetti et al. 2021).

3.3.3.3 | Malignancy Features. US demonstrated moderate to high inter-clinician agreement in assessing lesion boundaries, echogenicity, internal architecture, and vascularity (Ogura et al. 2013). SN and SP of US in detecting tumor spread beyond the lamina propria in the tongue were greater than 90% in one study (Rocchetti et al. 2021). In another study, the US was as sensitive and specific as MRI in detecting the expansion of tongue tumors across the midline (100% specificity and sensitivity for US and MRI), but was much less sensitive and more specific than MRI in detecting the spread of the tumor outside the tongue region (SN: 33.3% (US) vs. 100% (MRI); SP: 100% (US) vs. 75% (MRI)) (Takashima et al. 1989).

3.4 | Risk of Bias Assessment

The most frequent problems observed across studies were in the definition of inclusion criteria ($n = 8$), description of study subjects and setting ($n = 7$), the criteria used for measurement of the condition ($n = 7$), and outcome measurement ($n = 7$). The details are presented in Appendices S3 and S4.

4 | Discussion

This scoping review overviews the current knowledge regarding the potential of US to be used as an adjunct chairside tool in the diagnosis of oral lesions. US screening of benign and/or premalignant soft tissue lesions and intraosseous lesions showed high SN and SP. Additionally, there was a strong correlation of US-derived measurements of TT and DOI of malignancies with histopathological measurements. Previous systematic reviews showed agreement of the US ability to measure TT (Klein Nulent et al. 2018; Marchi et al. 2020; Tarabichi et al. 2019). A meta-analysis focused on tongue SCC demonstrated that US TT is highly correlated to HP TT, suggesting that US is valuable for preoperative estimation of tongue SCC TT (Tarabichi et al. 2019). A similar meta-analysis that evaluated US on oral SCC showed that it has high potential alongside MRI in preoperative assessment of TT as US TT showed good correlation with HP TT (Marchi et al. 2020). The accuracy of US to determine TT was also demonstrated in a meta-analysis of oral SCC in which a high correlation was found between US TT and HP TT in T1–T2 oral cancers (Klein Nulent et al. 2018). While TT measurement with US has been previously investigated, this scoping review presents additional parameters in which US can potentially improve diagnostic accuracy.

One study assessed the use of UHFUS in the diagnosis of benign soft tissue lesions, demonstrating strong accuracy values for all described categories of lesions (Izzetti et al. 2020). While the diagnostic efficacy of UHFUS has been demonstrated, this mode of US was also shown to be capable of recognizing characteristic biomarkers of each lesion type (growth type, mucosal thickness, echogenicity, and vascularization). The high sensitivity (100%) detected for mucosal growths suggests that all cases of lesions belonging to this category were identified and correctly classified by UHFUS. This study also highlights the potential of UHFUS in preoperative examination and as

an adjunct tool in the diagnostic workup for benign soft tissue lesions (Izzetti et al. 2020). Further studies exploring UHFUS are encouraged.

With respect to bony lesions, US was capable of identifying ameloblastoma proliferation based on cortical bone destruction with strong sensitivity and specificity; additionally, the use of CDFI was utilized to characterize tumor proliferation based on blood flow signaling (Lu et al. 2009). This study showcases that the assessment of mandibular odontogenic tumors may be facilitated with the use of US and may even provide a direction on the treatment approach, as it provides key information on tumor proliferation activity (Lu et al. 2009). In agreement, the high SN of US to detect bone lesions has been previously reported in a systematic review where jaw lesions were detected with 100% SN and 94% SP (Musu et al. 2016). This study used a 10–13 MHz probe and an extraoral scan protocol.

Our scoping review suggests that the malignant characteristics of oral lesions could be detected by the US. One study showed a high detection rate of tongue tumor spread by US (Rocchetti et al. 2021), and another study demonstrated that the US is comparable to MRI for detecting expansion of tongue tumors within the tongue itself (Takashima et al. 1989). Our findings allow us to conclude that US tumor detection is dependent on the size and location of the lesion. US has been shown to perform accurately in the detection of tongue tumors (Natori et al. 2008). One study further supports the performance of the US in detecting (base of tongue) BOT lesions (Faraji et al. 2018). This is in agreement with a previous systematic review on tongue SCC in which the US performed similarly with MRI in the estimation of TT of oral SCCs, with the majority of included studies being tongue tumors (Marchi et al. 2020). However, a different study demonstrated that US had significantly less sensitivity in detecting tumors compared to MRI (Takashima et al. 1989). These discrepancies in results indicate that more studies are needed to assess the performance of US on tongue lesions, and a stricter protocol for investigation is warranted. In terms of location, US was more sensitive in detecting whether a tumor had invaded the adjacent mandibular bone (93%) compared to conventional radiography (90%) and CT (86%) (Millesi et al. 1990).

The heterogeneity of US diagnostic metrics values between studies suggests that the type of US transducer, its frequency, and the acquisition protocol can impact the performance of the technology. Interestingly, one study reported differences in results depending on the transducer type (Lodder et al. 2011). In addition, US is heavily operator dependent and it requires a level of training. It is essential that studies focus on developing standardized imaging acquisition and assessment protocols and guidelines for the optimal use of US in dental practice. This will facilitate clinical implementation and validation of US as a chair-side tool in dentistry.

None of the included studies tested new handheld pocket US systems to assess the lesions. Although these devices have been previously tested for different purposes in medicine, with great diagnostic performance (Popat et al. 2024), there is limited investigation of the device in dental studies. Handheld US has several advantages over traditional cart-based ultrasound systems, including reduced costs and real-time imaging at the point of care (Andersen et al. 2019). Future research should explore the diagnostic potential of these systems, as their cost-effectiveness and compact size make them ideal candidates for use as chair-side tools, expanding their potential as a screening tool.

The findings from this scoping review indicate that the dental field could be heading in a similar direction as our medical colleagues, where US can be used as an initial method for assessing lesions and subsequently guide the clinician to make a more informed decision in the diagnostic workup and management of the patient (Rix et al. 2018). By providing valuable information about TT, DOI, malignant characteristics, and detection of tumor invasion, it holds significant potential as a chairside tool in dentistry. It can serve as a valuable complement in clinicians' decision-making processes on selecting further imaging modalities.

4.1 | Limitations, Knowledge Gaps, and Future Directions

This review identified knowledge gaps related to the diagnostic value of specific US systems, such as ultra-high-frequency US (UHFUS) and handheld pocket US. Additionally, there is a limited body of research evaluating the diagnostic potential of US for assessing benign lesions, including both intraosseous bony and soft tissue lesions. Further research is encouraged in the following topics: (1) exploring US applications in diverse regions of oral lesions, ranging from bony lesions to non-cancerous soft tissue lesions; (2) exploring different types of new US systems, including UHFUS and handheld pocket US.

4.2 | Clinical Translation of the Study Findings

Unlike other imaging modalities, US provides real-time visualization without exposing the patient to ionizing radiation. Its portability and accessibility make it particularly advantageous for point of care use (Shriki 2014). In contrast, MRI and CT imaging are typically limited to hospital-based settings and are often associated with significant wait times. For example, in countries like Norway and Canada, more than 60% of patients experience delays of over a month before obtaining a specialist appointment (OECD 2020).

These advantages position US as a promising tool for initial assessment of lesions in dental practice, as an additional chair-side tool. However, successful integration into routine care will require further investigation of the learning curve, operator training requirements, and standardization of protocols to ensure consistent diagnosis across dental practitioners.

5 | Conclusion

The potential of the US in assessing oral lesions was demonstrated by its high sensitivity and specificity in detecting lesion presence, location, TT, and DOI. As US continues to emerge as a valuable imaging modality, prospective studies are also needed to evaluate its clinical applicability, particularly in how its use in the initial assessment of lesions influences diagnostic accuracy and treatment decisions.

Author Contributions

Camila Pacheco-Pereira: conceptualization, writing – original draft, methodology, writing – review and editing, supervision, formal analysis. **Sheryn Villarey:** methodology, writing – review and editing, writing – original draft, formal analysis. **Swarna Yerebairapura Math:** methodology, writing – review and editing. **Konrad Lehmann:** writing – original draft, methodology, formal analysis. **Carlos Alberto Figueredo:** methodology, writing – review and editing. **Fabiana T. Almeida:** writing – original draft, conceptualization, investigation, methodology, writing – review and editing, supervision, formal analysis.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Appendix S1:** odi70107-sup-0001-AppendixS1.docx. **Appendix S2:** odi70107-sup-0002-AppendixS2.docx. **Appendix S3:** odi70107-sup-0003-AppendixS3.docx. **Appendix S4:** odi70107-sup-0004-AppendixS4.docx.