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INTRAORAL ULTRASONOGRAPHY FOR PERIODONTAL TISSUE EXPLORATION: WHAT IS REVIEW TALKING ABOUT TODAY?

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Abstract. Introduction. This systematic review aims to investigate the capabilities of ultrasound imaging in periodontal tissues exploration to visualize periodontal anatomical structures and to assess reliability in clinical evaluation using the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) guidelines. **Aim** of the study is to investigate the capabilities of ultrasound imaging in periodontal tissue research. **Material and Methods.** Databases, i. e., MEDLINE, PUBMED, MEDINNOVATION, and SCIENTIST were analyzed electronically to identify studies that have explored ultrasonography periodontal imaging, published within the timeframe from 2000 to March 2022. **Results and Discussion.** Our search delivered 245 records; upon making exclusions, a total of 15 papers was included in the present review. Various publications have shown the possibility of using intraoral ultrasound for a precise exploration of intraoral tissues and to perform measurements of periodontal structures. Studies argue that ultrasounds offer a prospect of the complete paradigm shift regarding the diagnosis and follow-up of periodontal diseases. However, there is currently no devoted clinical devices for periodontal ultrasound scanning. **Conclusion.** This anatomic region is still under-studied, and studies are needed to explore the large field of applications from periodontal assessment to reassessment of treatment, including surgery.
Keywords: ultrasonography; periodontal tissue; periodontology; high frequency ultrasound imaging; periodontal imaging
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ИНТРАОРАЛЬНОЕ УЛЬТРАЗВУКОВОЕ ИССЛЕДОВАНИЕ ПРИ ОБСЛЕДОВАНИИ ТКАНЕЙ ПАРОДОНТА: О ЧЕМ СЕГОДНЯ ГОВОРИТСЯ В ОБЗОРЕ?

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Реферат. Введение. Систематический обзор изучения возможностей ультразвуковой визуализации в области исследования тканей пародонта, для визуализации анатомических структур пародонта и оценки надежности клинической оценки с использованием рекомендаций PRISMA (предпочтительные элементы отчетности для систематических обзоров и мета-анализа). **Целью** текущего исследования является изучение возможностей ультразвуковой визуализации в области исследования тканей пародонта. **Материал и методы.** Был осуществлен электронный поиск по базам данных MEDLINE, PUBMED, MEDINNOVATION, SCIENTIST для выявления исследований, в которых изучалась ультразвуковая диагностика в области визуализации пародонта, опубликованных с 2000 по март 2022 года. **Результаты.** Результатом поиска стало 245 исследований; после исключения в настоящий обзор было включено в общей сложности 15 статей. Различные публикации показали возможность использования внутриротового ультразвука для точного исследования внутриротовых тканей и проведения измерений структур пародонта. Исследования утверждают, что ультразвуковое исследование открывает перспективу полной смены парадигмы в диагностике и последующем наблюдении за заболеваниями пародонта. Однако в настоящее время не существует клинического устройства, предназначенного для ультразвукового исследования пародонта. **Выводы.** Данная анатомическая область все еще недостаточно изучена, и необходимы исследования для изучения широкой области применения - от оценки состояния пародонта до переоценки лечения, включая хирургию.

Ключевые слова: ультразвуковое исследование, ткани пародонта, пародонтология, высокочастотная ультразвуковая визуализация, визуализация пародонта

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Introduction. Periodontitis is an inflammatory periodontium (tooth supporting tissues) disease of bacterial origin. It can be treated and controlled successfully, to avoid the progressive destruction of the tissues (the gum, the periodontal ligament, and the alveolar bone) [1]. A patient with periodontitis treated and stabilized with initial treatment nevertheless presents a risk of recurrence. Therefore, a continuous and individual assessment of patient's risks is necessary to monitor the non-evolution of the pathology [2]. Clinically, gingival health is defined by no bleeding on probing, no erythema or edema, no patient symptoms, and no attachment/bone losses [3]. The bleeding-on-probing test performed by a periodontal probe into the bottom of the sulcus is one element of monitoring the health or inflammation of the gingival tissues that is best documented in the literature [4]. This test is important because it has been shown that bleeding is an earlier sign of gingivitis than the visual signs of inflammation [5]. Bleeding on probing is an indicator of pathological phenomenon with presence of pocketing. On the other hand, it has been demonstrated that bleeding on probing provoked with pressures greater than 0.25 Newtons (N) results in false-positive readings in case of no pathology [6]. Despite this, periodontal probing has its limitations. This test is time-consuming, and operator-dependent errors are possible, such as incorrect angulation of the probe, excessive probing pressure on the gingival tissues, and incorrect reading of the measurement on the probe. An error in calculating the loss of attachment may occur. Reading errors can also result from interference from calculus, an overhanging restoration, or the crown contour. Other factors, such as the probe tip size, probe insertion angle, probe calibration accuracy, and inflammation degree in the periodontal tissues, affect the sensitivity and the reproducibility of the measurements [7]. Radiographic evaluation is an essential element of periodontal diagnosis. A radiograph of periodontal health includes a normal lamina dura, presence of bone in furcation areas, and 2 mm distance from the most coronal portion of the alveolar bone crest to the cementoenamel junction of the tooth [8]. Alveolar bone loss has the result of bone resorption in response of inflammatory process during periodontitis development. That is why it is very difficult to evaluate clinical periodontal health using routine radiographs only [3]. In view of these limitations, it is important to consider a new type of exploration being less time-consuming and easier to use in clinical practice. Since mid-1980s, some publications have presented ultrasound imaging applied to the exploration of the oral cavity in animals [9]. Ultrasonographic of the periodontal tissues could be an alternative to visualize periodontal structures and identify periodontal diseases with the detection of periodontal pockets and deep tissue inflammation. Ultrasonography is an ultrasonic medical imaging technique widely used in medicine. Ultrasounds used in medical ultrasonography are mechanical waves propagating within a medium. A mechanical wave is a local deformation which is propagated step by step in a solid, liquid, or gaseous medium [10,11]. Wave frequency corresponds to the number of periods per second in Hertz (Hz). Ultrasound ranges between 20 kHz and 200 MHz [12]. In medical imaging, ultrasound scanners are used within the range of 1 to 15 MHz. High-frequency ultrasound is defined as above 20 MHz [13]. This non-ionizing technique allows the soft-tissue investigation of human body through ultrasonic waves, which makes it possible to have resolutions ranging 0.4 to 2 mm. High-frequency techniques were used for medical applications, such as obstetric, cardiology, abdominal and muscular explorations [14–16]. Optimization in B-mode ultrasound has allowed achieving the best possible image quality in medical applications and develop a wide field of applications [17]. To obtain resolutions better than 0.1 mm, it is necessary to use ultrasound frequencies above 20 MHz. This field of ultra-high resolution ultrasound imaging has allowed exploring the skin [18] and the eye [19] for small animal imaging or angiology by the submillimeter resolution of smaller structures [16,20]. Ultrasound imaging has the potential to complement routine radiographic imaging in periodontology and provides instantaneous images of anatomical structures during the same examination. The practitioner can directly modify the incidence of the probe according to the tissue anatomy. It can be used without risk in all patients because it is not ionizing. Overcoming the phenomenon of superposition is possible with this type of imaging, unlike with 2D imaging [21]. For application in oral and dental imaging, its qualities depend on its ability to accurately capture these complex structures in a simple and rapid manner. These complementary methods are attractive because they are non-irradiating, non-invasive and patient-friendly since they allow direct reading of the images.

In these perspectives, studies showed the validity and reliability of ultrasonography in the measurement not only of gingival thickness but also of other periodontal structures which cannot be assessed through inspection and palpation [22,23]. A 25 MHz high-frequency resolution ultrasound probe, specially designed for intraoral applications, provides additional morphological information that is not accessible by conventional dental X-rays in daily dental practice with a large-scale of application in the diagnosis of pathologies [24].

Therefore, the aim of this systematic review was to investigate the possibilities of ultrasound imaging in the exploration of periodontal tissues to visualize periodontal anatomical structures and to assess reliability in clinical evaluation.

Materials and Methods. This systematic review was reported according to the PRISMA guidelines for Systematic Reviews [25]. Search Strategy. An electronic search was conducted through the MEDLINE (PubMed) database to identify publications that met the inclusion criteria. (9) The search was performed from 2000 up to March 2022, in order to identify the studies that explore the contribution of ultrasound imaging in periodontology, using the following search terms and keywords alone or in combination with the Boolean operator “AND”/“OR” according to the following equation (“alveolar ridge” [Mesh]) OR (“alveolar bone” [Mesh]) OR (“caries” [Mesh]) OR (“cementoenamel junction” [Mesh]) OR (“periodontal attachment” [Mesh]) OR (“periodontal probing” [Mesh]) OR (“periodontal charting” [Mesh]) OR (“dental implant” [Mesh]) OR (“periodontitis” [Mesh]) OR (“gingivitis” [Mesh]) OR (“periodontium” [Mesh]) AND (“sonography” [Mesh]) OR (“diagnostic ultrasound” [Mesh]) OR (“ultrasonography” [Mesh]). Study Detection. References of the eligible studies on the topic were manually checked, and two independent operators (F.D. and M.R.) screened the studies according to the inclusion/exclusion criteria. In case of disagreement, a 3rd reviewer (R.M.) was asked.

Inclusion and Exclusion Criteria.

We included experimental or clinical studies (longitudinal, cross-sectional, or randomized studies), in healthy patients or patients with periodontitis, that explored the link between ultrasound imaging and periodontology or oral tissues or explored an association between ultrasonography and histological or histometric characterization of periodontal tissues. According to the type of ultrasound imaging, we included only studies that presented a mode B ultrasound device. We excluded conferences, abstracts, reviews, and editorials.

Publications concerning the detection of carious lesions and publications relating the utilization of ultrasound to increase the healing and osseointegration potential of dental implants were not included, and we excluded publications related to other medical disciplines.

Each study that was meeting the inclusion criteria was analyzed from some aspects, such as authors, date of publication, study design, ultrasound device description, image classification, results, limitations, and discussion.

The list of titles and abstracts to identify the potentially relevant papers based on the inclusion criteria announced above were independently screened by two reviewers (F.D. and R.M.). If the abstracts were identified as non-relevant, the full studies were reviewed to decide if they should be included or not according to the inclusion criteria. A scan of the references of the previously selected articles completed the selection to improve the systematic review. When a discrepancy in the selection decision appeared, the two reviewers engaged in discussion until a consensus was found. If needed, a third reviewer (M.R.) resolved the possible conflicts concerning eligibility.

Results and Discussion. The initial studies retrieved from the databases were first selected, and studies that met the eligibility criteria were reviewed and analyzed. After 220 reading abstracts and 7 full articles, only 15 articles were selected from the 245 studies. The percentage of agreement between the reviewers was 100%.

The initial studies retrieved from the databases were first selected, and studies that met the eligibility criteria were reviewed and analyzed. After 220 reading abstracts and 7 full articles, only 15 articles were selected from the 245 studies. The percentage of agreement between the reviewers was 100%. The complementary detection did not result in the selection of new publication for analysis. Finally, a total of 15 articles was included in the analysis themes emerging, such as the evolution of trials, ultrasound device presentation, and the description of periodontal tissues using ultrasonography and comparative ultrasonography measurement. Studies included in the analysis were in vitro or ex vivo studies or clinical comparative trials using different tools to validate the use of ultrasound devices. *(Figure 1).*

Among the 15 studies included in the analysis (Figure 1), we were able to distinguish four common themes emerging such as the evolution of trials, ultrasound device presentation, the description of periodontal tissues using ultrasonography and comparative ultrasonography measurement. Studies included in the analysis were in vitro or ex vivo studies or clinical comparative trials using different tools to validate the use of ultrasound devices. Most of them applied low ultrasound frequencies.

Using ultrasonography for the visualization of the structures of the oral cavity was not an actual possibility, and publications existed for many years already. According to the periods of publications used in this review, we have noticed that there is a renewed interest in ultrasound technologies for periodontal exploration from the 2010s *(Figure 2).* There were only two publications between the years 2000 and 2010, whereas the number of publications increased after 2010 with 13 articles found.

According to our analysis, researchers have set up feasibility trials [23,33] for imaging and measuring the periodontal tissue. On the other hand, they have subsequently set up pilot trials [24,37] to evaluate the measurements provided by ultrasound images. In only one publication [29], ultrasonography is used to assess the size of the gingival tissue before and after professional periodontal cleaning.

Most of the studies were in vivo studies. In vitro studies used pig jawbones while ex vivo studies were performed on cadavers. *Figure 3* presents the proportion of studies according to the nature of the exploration. It should be noted that some studies have been realized in vitro and in vivo topic. This is the case, for example, in the studies of Sun et al., where measurements were realized on pig jawbones and on patients directly [36].

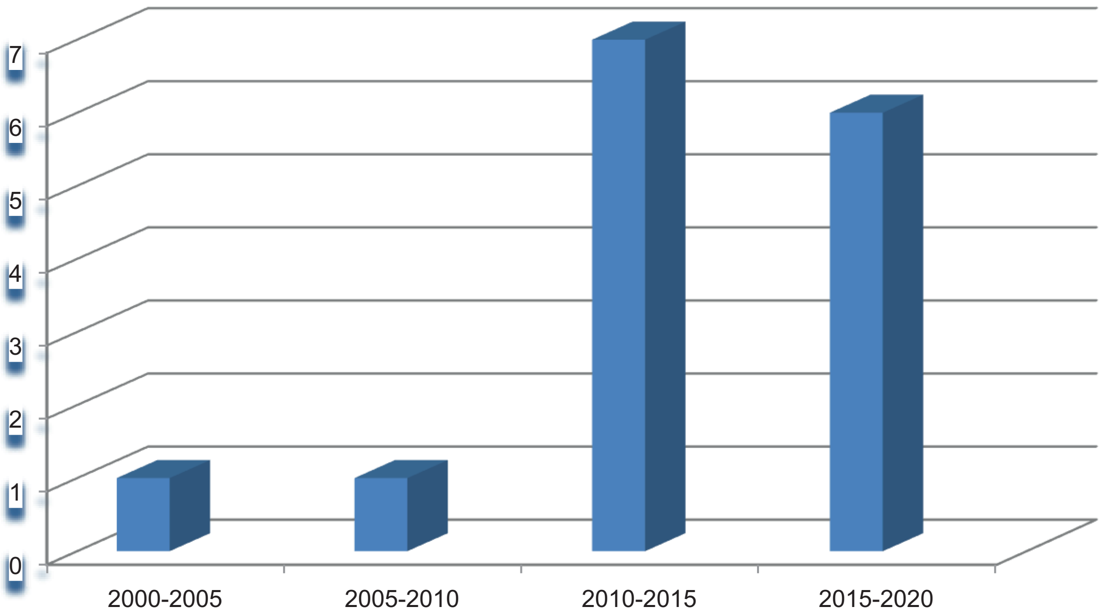

Figure 1. Number of publications over the time.
Рисунок 1. Количество публикаций за указанный период.

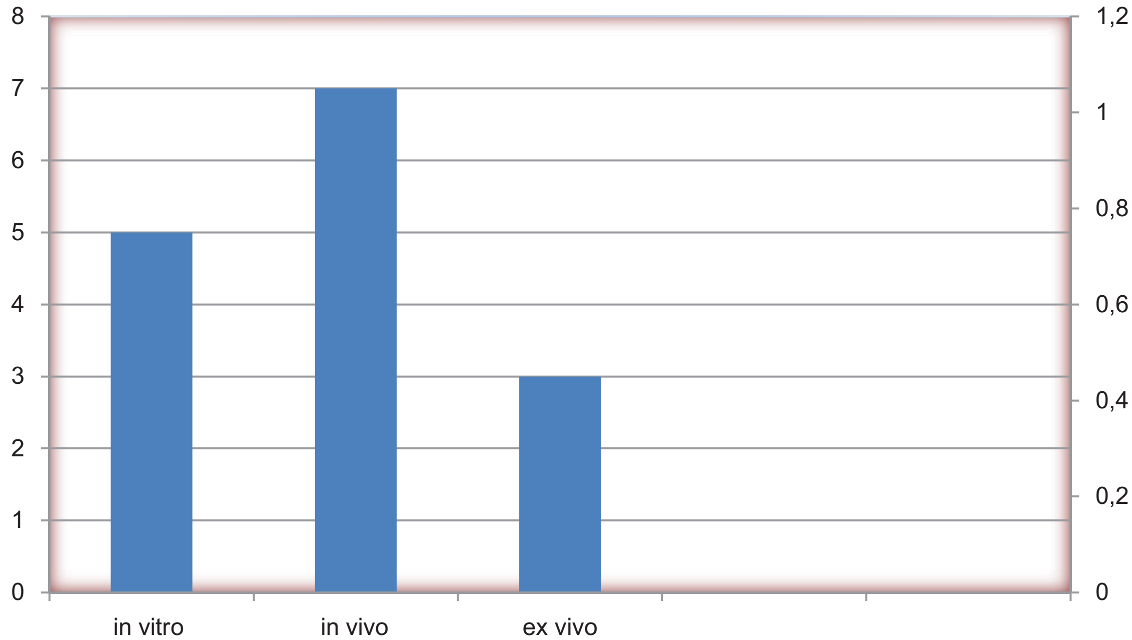

Figure 2. Number of publications by type of exploration.
Рисунок 2. Количество публикаций в разбивке по видам исследований.

The literature presents a set of ultrasound probes used for the majority with an intraoral approach. The probe is in contact directly with intra oral tissue for image production providing a sagittal slice. In two publications [28,33], we have found ultrasound probes for extra-oral approach. For the most part of them, ultrasound probes were not used for intra- oral utilization. In some studies, ultrasonography was used for monitoring skin [26,30] or used in small animals' studies [34].

In the study by Salmon et al., [24] the probe has been designed for intraoral use. It was manufactured on the model of a handpiece to use on all surfaces of the tooth. Tattan et al. [37] and Chan et al. [32,33] have used probes designed for intraoral use, as well. The prototypes for the oral cavity are smaller and used a head probe with a special angle allowing the tightest spaces of the oral cavity access. Components, such as the transducer, are necessarily miniaturized [24] for ease of use. Coupling agent is often a commercial water-like coupling gel. Coupling gels used were not specific to the oral environment or to use in periodontology.

Regarding the acoustic parameters of the probes, it should be remembered that periodontal imaging aims to image structures close to the probe head. The depth of exploration is less than 10 mm, and the structures to be explored are sub-millimetric in size. In this specific case, emission of frequencies needs to be between 15 MHz [33] up to 40 MHz [23,28] for best results. Beyond 20 MHz, we enter in the field of high frequency ultrasound to obtain high resolution images, with a resolution of less than 100 microns [24,34,35]. The images obtained can be modified to allow better readability as with X-ray images. For example, in the study by Chifor et al. [30], the authors have implemented an image processing technique that successfully delimits the sulcus automatically.

Within the periodontal tissue, bone structures are more echogenic because they reflect more ultrasound waves. Impedance rupture between hard and soft tissues allows them to be clearly distinguished. Therefore, hard tissues appeared whiter than soft tissues on the gray scale. First images need to be processed by computer. The authors added different colors according to the tissues to allow a good tissue differentiation. Periodontal tissues images from more recent publications, such as that of Tattan et al. [37] show better resolution with an adapted gray scale. Analysis of selected articles showed that ultrasound provided images of all periodontal structures, in pigs and humans, as listed in *Figure 3.*

Detection and classification of a periodontal disease is based on measurements of periodontal tissue. The studies almost systematically present a comparison between the ultrasound measurements of the periodontal tissue and the measurements obtained by procedures used in clinical routine (clinical probing), qualified as the gold standard. Publications show the measurements of sulcular depth [23], the thickness of the free gingiva [23], the thickness of the attached gingiva [26,28], the biological width [23,26,28], the level of the alveolar crest in relation to the cemento-enamel junction [21,27,28,32,36], the thickness of the cortical bone [26,32,42], the height of the interdental papilla [37,51], and the gingival thickness on the edentulous ridge [37, 39,58].

Studies on porcine jaws show direct transgingival measurements using an endodontic file [21,34,36], direct histological measurements [21,43,53] and direct clinical measurements using periodontal probe [21,23,28,32,34,37]. Conventional imaging methods have also been used: Cone Beam Computed Tomography (CBCT) [27,31,32,37], retro-alveolar radiography [28,45], and optical microscopy [27,30,35,57].

Some authors used statistical tools to establish the correlation between ultrasound measurements and other measurement techniques [27,28,30,32,36,37]. In the work by Zimbran et al. [23], the measurement of the sulcular space using the periodontal probe (gold standard) was not statistically different ($p < 0.05$) compared to the ultrasound measurement.

The greatest measurement variation between the two measurement techniques did not exceed 0.5 mm. Tsiolis et al. [21] calculated the repeatability coefficient for the ultrasound measurements in comparison with in vitro measurement. Ultrasound measurements were better. Chifor et al. [29] highlighted the reproducible nature of ultrasound measurements. The intra-observer ICC calculated for ultrasound measurements was 98.8 with $p < 0.001$ for the measurement of the distance between the cemento-enamel junction and the alveolar ridge. After publications analysis, ultrasonography demonstrates reproducibility and precision. Ultrasonography appeared reliable as compared to other measurement techniques (clinical and radiographic) in periodontal tissue application.

Conclusions. Interest in intraoral ultrasound technologies has grown over the past decade. Various publications highlighted a reliable means of imaging allowing a precise exploration of the periodontal tissues offering the possibility of carrying out measurements

Alveolar crest	Mucogingival line	Biological width
Alveolar bone	Gingival tissue	Sulcus
Cortical bone	Oral mucosa	Cemento-enamel junction

Figure 3. Types of periodontal tissues imaged by US scanning.
Рисунок 3. Типы тканей пародонта, полученные с помощью УЗИ.

of the periodontal structures themselves or between them. However, there is currently no dedicated clinical device for periodontal ultrasound scanning. As of now, the use of ultrasound in periodontology remains confined to the area of research. Ultrasound offers a prospect of the complete paradigm shift regarding the diagnosis and follow-up of periodontal diseases, by reducing the examination time of periodontal pockets, being more reproducible and more efficient. In addition, implementing the software, including an artificial intelligence system allowing the direct periodontal pocket measurement and the early inflammation detection in deep periodontium, could facilitate diagnosing and ensure the early treatment of periodontal diseases. Moreover, this new approach could allow an evaluation of the initial treatment and permit more reliable periodontal maintenance. In addition, the direct measurement of periodontal pockets without ionizing radiation is a major advance on the complementary examination allowing reducing the number of periapical X-rays. Periodontal ultrasound is not intended to replace the conventional techniques of evaluating periodontal tissues. However, the associated opportunities are immense with a lot of applications from periodontal assessment to the reassessment treatment, including surgery.

Прозрачность исследования. *Исследование не имело спонсорской поддержки. Автор несет полную ответственность за предоставление окончательной версии рукописи в печать.*

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